SMALL BUSINESS INNOVATION RESEARCH TO SUPPORT AGING AIRCRAFT

Priority Technical Areas and Process Improvements

NATIONAL RESEARCH COUNCIL

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Priority Technical Areas and Process Improvements

**Committee on Small Business Innovation Research
to Support Aging Aircraft
National Materials Advisory Board
Division on Engineering and Physical Sciences
National Research Council**

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Preface

The Small Business Innovation Research (SBIR) program was created in 1982 by the Small Business Innovation Development Act. The program is designed to stimulate technology innovation by small businesses, provide technical and scientific solutions to challenging problems, and encourage the marketing of the resulting new technologies in the private sector. Federal agencies with more than $100 million in extramural research and development (R&D) are required to allocate 2.5 percent of their research budgets to small businesses. Such funds from all federal agencies amounted to approximately $1.1 billion in fiscal year 1998. The U.S. Department of Defense (DOD) has the largest single SBIR program ($540 million), approximately 40 percent of which comes through Air Force channels.

Determining how to allocate these funds to the myriad Air Force agencies requesting funding is a difficult challenge. Historically, the Air Force SBIR program has been defined largely by the R&D directorates of the Air Force Research Laboratory. Many of the resulting programs were focused on solving important problems identified by customers within the Air Force, but these customers were not consistently brought into the SBIR allocation process even though they contributed resources to the Air Force SBIR pool. More customer participation would ensure not only that important problems are being addressed, but also that effective processes are put in place to transition new technologies. The need for more active customer participation and effective technology transition was recognized at the DOD level to be an important SBIR program issue across all the services and defense agencies. Formal direction to remedy this situation DOD-wide was issued in 1999 by the DOD undersecretary of defense for acquisition and technology. In response to this guidance, the Air Force significantly revised its SBIR processes, bringing in all the contributing customers, including the aging aircraft system program offices and Air Force air logistics centers, as the direct sustainment community stakeholders.

Another recent development is the recognition that aging aircraft will remain the backbone of the operational force for many years to come. Although some aircraft will be retired and replaced with new aircraft, most replacements are several years away. For many older aircraft, no replacements are planned, and some are expected to remain in service for another 25 years or more.

Recognizing the challenges of managing and operating an aging fleet, the Air Force, in 1997, sponsored a National Research Council (NRC) study under the auspices of the National Materials Advisory Board (NMAB), *Aging of U.S. Air Force Aircraft*. At about the same time, a new Aging Aircraft Program (funded by

Program Element 6.5, or Engineering and Manufacturing Development) was launched at the Aeronautical Systems Center at Wright-Patterson Air Force Base, Ohio. The program was meant to complement the ongoing aging aircraft program (funded by Program Element 6.2, or R&D) at the Air Force Research Laboratory by providing funding for technology transition for technologies developed at the laboratory and elsewhere.

At the request of Blaise Durante, deputy assistant secretary, management policy and program integration, Office of the Assistant Secretary of the Air Force for Acquisition, the NRC formed the Committee on Small Business Innovation Research to Support Aging Aircraft to conduct a second study. The main purpose of the study was to determine how SBIR programs could be used to improve the development and implementation of technologies associated with the cost-effective maintenance and operation of aging aircraft. The committee did not examine uses of SBIR funds for technologies other than for aging aircraft.

Committee members were chosen for their extensive knowledge and understanding of mechanical, chemical, and metallurgical processes, inspection and repair, management and implementation of the SBIR program, and the role of small business in technology development and implementation. The four committee meetings included briefing sessions to review the national goals of the SBIR program and to review existing aging aircraft programs and the SBIR process. The committee also attended and participated in the 2000 Aging Aircraft Conference held in St. Louis, Missouri. Finally, the committee met at the NRC Study Center in Woods Hole, Massachusetts, to develop the conclusions and recommendations presented here and to compile the rough draft of this report.

The chair wishes to thank the committee members for their enthusiasm, dedication, and service, the participants for their hard work, insight, excellent presentations, and stimulating discussions, and the staff of the National Materials Advisory Board, especially Arul Mozhi, study director, and Pat Williams and Judy Estep, senior project assistants, for their coordination, cooperation, and assistance throughout the entire process, including the editing and publication of this report. The chair also wishes to recognize the outstanding liaison services of Dan Brewer and Mike Zeigler of the Aging Aircraft Technologies Office, Wright-Patterson Air Force Base. Mr. Brewer's coordination of presentations and information from the Air Force customer groups was invaluable.

Comments and suggestions can be sent via e-mail to NMAB@nas.edu or by fax to (202) 334-3718.

Harry A. Lipsitt, *chair*
Committee on Small Business
Innovation Research to Support Aging
Aircraft

Acknowledgments

The Committee on Small Business Innovation Research to Support Aging Aircraft thanks the participants in the study meetings, the principal means of gathering data for this study. The information from and insights of the participants were invaluable. Presenters included Blaise Durante, Ed Davidson, Maj. Karl Hart, Jack Lincoln, Lt. Andrew Lofthouse, Lt. Col. Vishu Nevrekar, Dave Uhrig, U.S. Air Force; Dan Brewer, Charlie Buynak, Marvin Gale, Steve Guifoos, Capt. Mike Myers, Clare Paul, Deb Peller, Scott Theibert, Madie Tillman, U.S. Air Force Research Laboratory; Thomas Munns, ARINC; Ron Lofaro, Federal Aviation Administration; and Dale Moore, U.S. Navy. The committee is particularly grateful to Blaise Durante, Dan Brewer, and Michael Zeigler for their support.

This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the authors and the NRC in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report: James Chern, NASA-Goddard Space Flight Center; David R. Clarke, University of California-Santa Barbara; Carl Handsy, U.S. Army Tank Automotive and Armaments Command; James Intrater, Integer Engineering Corporation; Alan Miller, Boeing Commercial Airplane Group; Thomas Munns, ARINC; and Thomas Savell, Dynamic Analysis and Testing Associates.

While the individuals listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Gerald Dinneen, Honeywell, Inc. (retired), appointed by the NRC's Report Review Committee, who was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of the report rests solely with the authoring committee and the institution.

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Executive Summary

The U.S. Air Force requested that the National Research Council (NRC), through the National Materials Advisory Board, conduct a study to determine how Small Business Innovation Research (SBIR) programs could be used more effectively to develop and implement technologies to improve the cost-effectiveness of maintenance and operation of aging aircraft. The Committee on Small Business Innovation Research to Support Aging Aircraft was established to:

- review the overall goals and specific program objectives of the Air Force aging aircraft program, as well as current SBIR projects related to aging in the areas of structural integrity, corrosion, coatings, nondestructive investigation, and maintenance and repair
- review technical and administrative guidelines and requirements for the Air Force SBIR program
- review SBIR programs by other organizations (e.g., the Navy, the Federal Aviation Administration, the National Aeronautics and Space Administration, and the Ballistic Missile Defense Organization) that could be applicable to aging aircraft
- identify critical technology areas that (1) would address the technical goals and priorities of the Air Force aging aircraft program and (2) could be included in SBIR programs
- recommend criteria for selecting SBIR topics in the identified technology areas

The committee did not examine uses of SBIR funds for technologies other than for aging aircraft. It met four times. At the first meeting, the committee reviewed the national goals of the SBIR program and was given an overview of the Air Force SBIR and aging aircraft programs. At the second meeting, the committee reviewed the details of the Air Force's existing aging aircraft programs and the SBIR process. The committee then attended the 2000 Aging Aircraft Conference held in St. Louis,

Missouri, May 15–18, 2000, to inform delegates about the study and to discuss the SBIR program with them. The committee also held a closed session, the third meeting, at which members exchanged observations, ideas, and conclusions. At the fourth meeting, the committee agreed on the conclusions and recommendations for this report.

This report summarizes the committee's overall evaluations and recommends how the Air Force's SBIR program can support aging aircraft. Chapter 1 is an introduction to the study. Chapter 2 is a discussion of the Air Force's aging aircraft program; the discussion includes technical areas and interagency issues. Chapter 3 is a discussion of the Air Force SBIR program and SBIR topics on aging aircraft. Chapter 4 covers technical areas that could be advanced significantly by the SBIR program. Chapter 5 is a discussion of SBIR process improvements.

BACKGROUND

Aging Aircraft Fleet

Aircraft more than 20 years old are the backbone of the Air Force's total operational force. Some of these aircraft will be retired and replaced with new aircraft, but their replacements are at least several years away. Replacements for the remaining older aircraft are not even planned. Some aircraft that have been in service for more than 25 years are expected to remain in active service for another 25 years or more. The enormous cost of replacing existing planes is one of the prime reasons for this situation. If the life of existing planes can be extended at reasonable cost, then substantial savings, or at least substantial cost deferments, can be realized. The extended service of older aircraft so far has been possible only through aggressive maintenance and repair and aircraft modification programs. But these costly, labor-intensive measures depend on high levels of skill and craftsmanship.

One of the most pervasive problems is corrosion. The implementation of advanced technologies to prevent corrosion would significantly improve field and depot maintenance procedures and help to ensure reliable, safe operation of older aircraft.

Small Business Innovation Research

The SBIR program, created in 1982 by the Small Business Innovation Development Act, is designed to stimulate technology innovation by small, private-sector businesses, provide technical and scientific solutions to challenging problems,

and encourage small businesses to market new technologies in the private sector. Federal agencies with more than $100 million in extramural research and development (R&D) are required to allocate 2.5 percent of their research budgets to small businesses. In 1998, approximately $1.1 billion was allocated. The U.S. Department of Defense (DOD), with $540 million, has the largest single program; approximately 40 percent of that amount comes from Air Force channels.

Determining how to allocate these funds to the myriad Air Force agencies requesting funding is a difficult challenge. Historically, the Air Force SBIR program has been defined largely by the R&D directorates of the Air Force Research Laboratory. Many of the resulting programs were focused on solving important problems identified by customers within the Air Force, but these customers were not consistently brought into the SBIR allocation process even though they contributed resources to the Air Force SBIR pool. More customer participation would not only ensure that important problems are being addressed, but also that effective processes are put in place to transition new technologies. The need for more active customer participation and effective technology transition was recognized at the DOD level to be an important SBIR program issue across all the services and defense agencies. Formal direction to remedy this situation DOD-wide was issued in 1999 by the DOD undersecretary of defense for acquisition and technology. In response to this guidance, the Air Force significantly revised its SBIR processes, bringing in all the contributing customers, including the aging aircraft system program offices and Air Force air logistics centers, as the direct sustainment community stakeholders.

AIR FORCE AGING AIRCRAFT PROGRAM

To varying degrees, all older aircraft have encountered, or can be expected to encounter, aging problems, including fatigue cracking, stress-corrosion cracking, corrosion, and wear. Through the Aircraft Structural Integrity Program and through durability and damage-tolerance assessments of older aircraft, the Air Force has identified many potential problems, developed aircraft-tracking programs, developed force structural-maintenance plans, and taken maintenance actions to ensure the safety, readiness, and extended life of its aircraft. The continued operation of older aircraft depends on improved inspections, evaluations, and maintenance. Recognizing the challenges of managing and updating an aging fleet, the Air Force sponsored an NRC study in 1997, *Aging of U.S. Air Force Aircraft*, which identified promising technologies and research opportunities for addressing the structural issues critical to the aging of fixed-wing aircraft, particularly with reference to fatigue, corrosion, inspection, and repair (NRC, 1997). The report recommended that the management and oversight of all aging aircraft functions at the Wright-Patterson Air

Force Base be placed under the guidance of a single technical leader. In accordance with this recommendation, the Air Force created the Aging Aircraft Technologies Team (AATT), which includes representatives of the three technical areas related to aging aircraft: science and technology, technology transition, and systems engineering (structural assessments). The goal of the AATT is to coordinate activities to address identified needs in the areas of widespread fatigue damage, corrosion-fatigue interactions, structural repairs, dynamics, health monitoring, nondestructive evaluation and inspection (NDE/NDI), and various aircraft subsystems.

The aging aircraft program has adopted the following technical objectives:

- correcting structural deterioration that could threaten aircraft safety
- preventing or minimizing structural deterioration that could become an excessive economic burden or could adversely affect force readiness
- predicting, for the purpose of future force planning, when the maintenance burden will become so high, or the aircraft availability so poor, that retaining the aircraft in the inventory will no longer be viable

A major new aging aircraft program under AATT's oversight is the Technology Transition Program. The program budget was $5 million in 1999 and $14 million in 2001, and it is expected to increase. The program funding that comes from Program Element 6.5, or Engineering and Manufacturing Development (PE 6.5 - EMD), is the only new funding that has been made available since the 1997 NRC report, and its impact on the total Air Force aging aircraft situation has been positive. In fact, many of the recommendations in the NRC report have been acted upon, and more will be addressed in the years to come. The Air Force has made significant progress in the areas of widespread fatigue damage, dynamics, and structural repairs. However, not enough emphasis has been put on the areas of corrosion, corrosion-fatigue, stress-corrosion cracking, and automated NDE/NDI.

PRIORITY TECHNICAL AREAS AND PROCESS IMPROVEMENTS

As a result of its deliberation and discussion, the committee developed several recommendations, which are presented in Chapters 2 through 5 of this report. The technical areas in which the aging aircraft program could more effectively take advantage of the capability or potential of the SBIR program are summarized in Chapter 4. The committee concluded that SBIR could be most beneficial if projects were concentrated in a few technical areas, such as localized corrosion and NDE/NDI.

Recommendation. The committee recommends that more emphasis should be placed on using the Small Business Innovation Research (SBIR) program in the near term to solve problems related to localized corrosion (including galvanic corrosion and corrosion fatigue) and nondestructive evaluation and inspection (NDE/NDI). Solutions to the problems of (1) modeling and understanding galvanic corrosion, stress-corrosion cracking, corrosion fatigue, and all the other insidious forms of corrosion and (2) developing tools for NDE/NDI and software to analyze data in these areas should be solicited from the small business community. Because many of the innovations will be specific to the Air Force, the end user (in the Air Force) should be involved in the Phase I and Phase II award process. In addition, if the innovation is Air Force-specific, non-SBIR funding for Phase III may be an Air Force responsibility.

This report focuses on technical approaches to using SBIR to support aging aircraft. In this context, the committee also reviewed Air Force SBIR administrative processes in some detail and determined that changes in certain processes would help the Air Force to address aging aircraft technologies, as well as other technology areas. Although the committee did not consider all potential SBIR process improvement options and alternatives, it offers in Chapter 5 some recommendations in several areas—including the selection of SBIR topics, the transition from Phase I to Phase II, the use of white papers in preparation for Phase I, management and the timing of contract awards, customer participation, and outreach and communication—for careful consideration by the Air Force. Because only SBIR projects related to aging aircraft were considered, the Air Force will have to determine if these recommendations on SBIR administrative processes apply to other aspects of its SBIR program as well.

1

Introduction

AGING FLEET

The U.S. Air Force has many aircraft that are 20 to 35 years old (and older), which constitute the backbone of the total operational force. The Air Force plans to retire these aircraft and replace some of them with new aircraft, but their replacements are at least several years away. Replacements for the remainder are not even planned. Because of the enormous cost of replacing existing planes, some aircraft that have been in service for more than 25 years are expected to remain in active service for another 25 years or more. If the life of existing planes could be extended at reasonable cost, the Air Force would realize substantial savings or, at least, cost deferments. Protracted depot operations and maintenance (O&M) and other life extension programs decrease fleet readiness, and commanders have been reluctant to remove planes from service unless their timely return can be guaranteed.

Extended service lives of older aircraft have been possible only through aggressive maintenance and repair and aircraft modification programs, which can be costly and labor intensive and depend on high levels of skill and craftsmanship. One of the most pervasive problems is corrosion. Air Force surveys of the cost of corrosion in 1990 and 1997 showed that corrosion-driven maintenance costs the Air Force many hundreds of millions of dollars annually, and these costs are steadily increasing (Cooke et al., 1998). The implementation of advanced technologies to prevent corrosion would significantly improve field and depot maintenance procedures and help to ensure the reliable, safe operation of older aircraft.

PAST REPORTS

The Air Force has been well aware of the challenges of managing and updating an aging fleet for some time. In 1997, the Air Force sponsored a National Research Council (NRC) study, *Aging of U.S. Air Force Aircraft*, which identified promising technologies and research opportunities for addressing critical structural issues surrounding the aging of fixed-wing aircraft, particularly fatigue, corrosion, inspection, and repair (NRC, 1997). That report recommended that the Air Force (1) implement near-term actions (3 to 5 years) to improve the maintenance and management of aging aircraft; (2) sponsor near-term research

and development (R&D) to support the near-term actions; and (3) initiate a long-term (more than 5 years) R&D program to develop mature technologies. The highest-priority research issues were reduction of maintenance costs, improvement of force readiness (particularly in the areas of corrosion prevention and control and prevention of stress corrosion cracking), and the development of automated, nondestructive evaluation methods. More recently the Steering Committee for Government-Industry Partnerships of the Board on Science, Technology, and Economic Policy of the NRC published the proceedings of a symposium held on February 28, 1998, in Washington, D.C., *The Small Business Innovation Research Program: Challenges and Opportunities* (NRC, 1999a), and *The Small Business Innovation Research Program: An Assessment of the Department of Defense Fast Track Initiative* (NRC, 2000). The present study is another indication of the Air Force's concern about the problems of aging aircraft.

AGING AIRCRAFT PROGRAM

In varying degrees, all older aircraft have encountered, or can be expected to encounter, aging problems, including fatigue cracking, stress corrosion cracking, corrosion, and wear. Through the Aircraft Structural Integrity Program (ASIP) and through durability and damage-tolerance assessments of older aircraft, the Air Force has already identified many potential problems, developed aircraft-tracking programs, developed force structural-maintenance plans, and taken maintenance actions to ensure safety and readiness and extend the service life of the aircraft. However, the continued operation of older aircraft will depend on improving inspection, evaluation, and maintenance. The 1997 NRC report recommended that the management and oversight of all aging aircraft functions at the Wright-Patterson Air Force Base be placed under the guidance of a single technical leader. In accordance with this recommendation, the Air Force created the Aging Aircraft Technologies Team (AATT), which includes representatives of the three technical areas related to aging aircraft: science and technology, technology transition, and systems engineering (structural assessments). The goal of the AATT is to coordinate activities to address identified needs in the areas of widespread fatigue damage, corrosion-fatigue relationships, structural repairs, dynamics, health monitoring, nondestructive evaluation and inspection (NDE/NDI), and various aircraft subsystems.

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SMALL BUSINESS INNOVATION RESEARCH PROGRAM

The Small Business Innovation Research (SBIR) program was begun by the National Science Foundation (NSF) in the late 1970s. Recognizing that small businesses could play a key role in meeting the research needs of the federal government, Congress enacted a program in 1982 that included all federal agencies that fund more than $100 million in extramural research. The SBIR program was reauthorized in 1986, 1992, and 2000. The funding for fiscal year 2000 (FY00) is calculated as a set-aside of 2.5 percent of the extramural research budget for each agency. Currently, extramural research funded by the federal government amounts to about $60 billion, $1.2 billion of which comes from the SBIR program.

In 1983, Congress also enacted a pilot program, the Small Business Technology Transfer (STTR) program, which it reauthorized in 1997 and 1998 until 2001. The SBIR program allows partnerships in the form of subcontracts; the STTR program mandates partnerships with academia, federally funded research and development centers, and other nongovernmental organizations. The STTR set-aside is 0.15 percent, and agencies with more than $1 billion of extramural research participate.

Currently, 10 federal agencies participate in the SBIR program; the top 5 also participate in the STTR program. In decreasing order of funding, the 10 agencies are the Department of Defense (DOD), the Department of Health and Human Services, the National Aeronautics and Space Administration (NASA), the Department of Energy, NSF, the Department of Agriculture, the Department of Commerce, the Environmental Protection Agency (EPA), the Department of Transportation, and the Department of Education. The aim of the SBIR program, as stated in the legislation, is to:

- increase private-sector commercialization of technology developed through federal R&D funds
- increase small business participation in federal R&D
- improve the federal government's dissemination of information about the SBIR program, particularly information on participation by female- and minority-owned small businesses

Agencies promote these aims to different degrees. Grant-awarding agencies, such as the NSF, emphasize private-sector commercialization; contracting agencies, such as DOD, emphasize increased participation in R&D to overcome specific technical needs. The SBIR program has been subjected to several reviews by the Government Accounting Office and independent organizations, and after almost two decades of existence, the SBIR program has been given a favorable overall assessment.

The SBIR program is intended to stimulate technology innovation by small private-sector businesses, provide technical and scientific solutions to challenging problems, and encourage small businesses to market new technologies in the private sector. DOD has the largest SBIR program at $540 million, approximately 40 percent of which comes from the Air Force.

SBIR funds are awarded in two phases. During Phase I, the technical feasibility of a new concept is validated; this phase lasts from 6 to 9 months and may cost as much as $100,000. Phase II is the R&D phase; this phase can last as long as 2 years and costs as much as $750,000. Phase III, the commercialization of the Phase II results, requires private-sector or other non-SBIR funding; securing non-SBIR funding for Phase III technologies mainly of interest to DOD and the necessary customer commitments for successful transition is a considerable challenge and is not usually included in DOD's plans.

It is important to note that the Air Force sustainment community is not a direct contributor to the SBIR resource pool because O&M procurement accounts are not subject to the SBIR set-aside. The Air Force has chosen, however, to make the air logistic centers participants in the program on the assumption that SBIR programs properly focused could address critical technical needs of aging aircraft. How to meet these needs through SBIR funding is the subject of this report.

STATEMENT OF TASK AND METHODOLOGY

The primary objective of this study was to determine how SBIR programs could be used more effectively to develop and successfully transition technology that would promote the cost-effective maintenance and operation of aging aircraft. The committee did not examine the use of the SBIR funds for other technologies. The study is restricted to the needs of the aging aircraft community and

specifically to aging airframes. It focuses on technical approaches to using SBIR to support aging aircraft. In this context, the committee also reviewed Air Force SBIR administrative processes in some detail and determined that changes in certain processes would help the Air Force to address aging aircraft technologies as well as other technologies. The committee did not consider all potential SBIR process improvement options and alternatives, but it offers in chapter 5 some recommendations for careful consideration by the Air Force. Because only SBIR projects related to aging aircraft were considered, the Air Force will have to determine if these recommendations on administrative processes apply to other aspects of its SBIR program.

The objective of this study was to identify ways the Air Force Research Laboratory and the Aging Aircraft Technologies Team could use the SBIR program more effectively to develop technologies that would address the problems of inspecting, characterizing, operating, and maintaining aging aircraft. The committee was established to do the following:

- review the goals of the Air Force aging aircraft program and current SBIR projects related to aging in each technology area, including structural integrity, corrosion, coatings, nondestructive investigation, and maintenance and repair
- review technical and administrative guidelines and requirements for the Air Force SBIR program
- review applicable SBIR programs of other organizations (e.g., the Navy, the Federal Aviation Administration (FAA), NASA, and the Ballistic Missile Defense Organization) that could be applicable to aging aircraft
- identify critical technology areas that (1) address the technical goals and priorities of the Air Force aging aircraft program and (2) could be advanced significantly by SBIR programs
- recommend criteria for selecting SBIR topics in the identified technology areas

The NRC's National Materials Advisory Board appointed a committee of experts in research management, SBIR requirements, materials and processes, structural mechanics, fracture mechanics, corrosion, nondestructive evaluation, and maintenance and repair procedures. Appendix A provides brief biographies of the committee members.

The committee met four times. At the first meeting, in Washington, D.C., January 25-26, 2000, the committee reviewed the national goals of the SBIR program. The second meeting, in Dayton, Ohio, March 14-15, 2000, was focused on a review of existing aging aircraft programs and the SBIR process. The third meeting included participation in the 2000 Aging Aircraft Conference, held in St. Louis, Missouri, May 15-18, 2000, to provide a broad perspective on national and

international programs (UTC, 2000). More than 600 participants from several countries attended the conference, indicating that aging aircraft are a worldwide concern. The plenary talks highlighted the seriousness of the problem in both military and civilian aviation. These talks complemented the three simultaneous sessions that followed. The committee chair made a presentation at the plenary session of the conference to acquaint the delegates with the committee's mission, goals, and progress, and conference delegates were invited to meet informally with the committee to discuss their needs and understanding of the SBIR program as it applied to aging aircraft. The committee also held a closed session at the conference, during which several observations and conclusions were discussed. At the fourth committee meeting, held at the NRC study center in Woods Hole, Massachusetts, June 21-22, 2000, the committee agreed on the conclusions and recommendations of this study. (See Appendix B for meeting agendas.)

REPORT CONTENT

This report summarizes the committee's overall evaluation and offers recommendations on how the Air Force's SBIR program can support aging aircraft. Chapter 2 discusses the Air Force's aging aircraft program, aging aircraft technical areas, and interagency issues. Chapter 3 discusses the Air Force SBIR program and topics on aging aircraft. Chapter 4 outlines the technical problems that could be improved significantly by the SBIR program. Chapter 5 discusses improvements in SBIR processes that could allow them to better address the technical areas relevant to aging aircraft, as well as all other technical areas.

2

Air Force Aging Aircraft Program

This chapter provides (1) a discussion of the Aging Aircraft Technologies Team (AATT), which was formed in response to the 1997 NRC study on U.S. aging aircraft and (2) discussion of technical areas and interagency technical issues.

AGING AIRCRAFT TECHNOLOGIES TEAM

The AATT was formed in response to a recommendation of the Committee on Aging of U.S. Air Force Aircraft that the Air Force "appoint a single knowledgeable and experienced technical leader responsible for the oversight of the aging aircraft activities" (NRC, 1997, p. 48). The AATT provides the framework for management, programming, and technology development and transition. The team has established three program groups: science and technology (S&T), technology transition, and structural assessments. AATT is responsible for identifying R&D needs and opportunities to support the continued operation of aging aircraft and to implement that research to ensure flight safety and reduce maintenance and repair costs. To carry out its responsibilities, AATT coordinates with the major commands, depots, field operations, and airplane single managers. The structural assessment group does not manage program funds but does provide engineering expertise in structural analyses and systems engineering. The systems engineers work with the other two groups under a single technical leader from the Aeronautical Systems Center (ASC) to develop all S&T and acquisition programs for aging aircraft.

Program Scope And Objectives

The 1997 NRC report recommended that the Air Force adopt a three-pronged plan of action: (1) near-term action (3 to 5 years) to improve the maintenance and management of aging aircraft; (2) near-term R&D to support the near-term actions; and (3) long-term R&D. The highest-priority research issues were technologies that would lead to reduced maintenance costs, improved force readiness (by prevention and/or control of corrosion and stress corrosion), and

automated NDE/NDI methods. A properly focused SBIR program could address some of these critical needs.

Aging affects every element of the aircraft system: airframe, engines, avionics, and subsystems. AATT originally limited its scope to airframes, but it is considering expanding its scope to include subsystems. Based on input and participation from the aging aircraft community, AATT identifies problems that have an R&D solution, matches these problems with a technology, and then supports development and transfer of the technology to the user. Companion programs in ASC and AFRL with substantial resources are addressing other component areas, such as propulsion systems and avionics.

AATT has adopted the following guiding principles: (1) meeting the needs of Air Force aircraft; (2) improving flight safety, reducing maintenance costs, and enhancing availability of aircraft; (3) remaining output-oriented and cost-focused; (4) developing technologies that can be transferred; and (5) augmenting the capability in industry and government.

AATT's specific objectives are (1) to develop and field technologies to extend the life and/or reduce the cost of aging systems; (2) to ensure flight safety and avoid catastrophic failures; (3) to reduce maintenance and repair requirements and their associated costs; and (4) to increase force readiness.

Processes

AATT has established several key processes to implement its programs and to develop the partnerships necessary for effective technology transition (see Figure 2-1). These key processes are:

- annual durability assessment surveys led by ASC
- establishment of the Aging Aircraft Working Group, led by ASC
- initiation of the aging aircraft Integrated Technology Thrust Program (ITTP), led by AFRL

The annual surveys cover all aging aircraft systems. An ASC/AFRL team, led by the technical leader, visits all Air Force air logistics centers (ALCs) during the summer to review the status of structures and subsystems of all aircraft, whether they are maintained by the Air Force or by contractor logistics support. The results of these surveys are compiled and summarized in an issues and requirements document (ASC/AFRL, 1999).

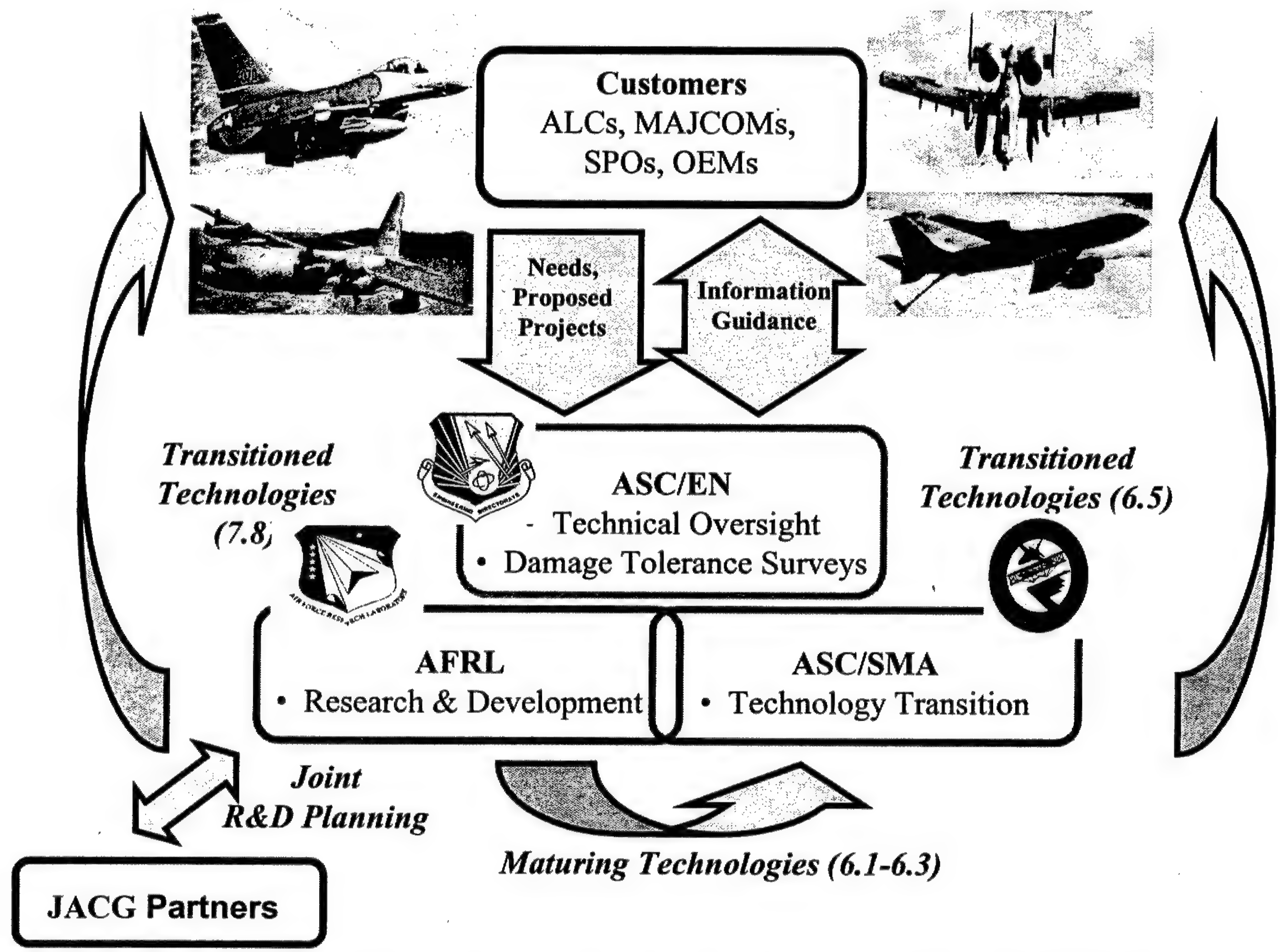


FIGURE 2-1 Solving aging aircraft problems with cost-focused methods—the AATT process. Figure courtesy of Air Force Aeronautical Systems Center.

At the beginning of each calendar year, ASC launches a dialogue with the ALCs, the system program offices (SPOs), the Major Commands (MAJCOMs), AFRL, and industry to obtain specific PE 6.5 program recommendations for the next fiscal year. This dialogue also includes the small business community and others (such as academia) who may have innovative ideas but may not be aware of aging aircraft issues. The results are brought to the Aging Aircraft Working Group in the spring, where a prioritized list of acquisition programs is developed and approved by ASC leadership.

By designating aging aircraft as an ITTP within the sustainment integrated technology thrust, AFRL has enabled the coordination of management and programming among the AFRL directorates, principally the AFRL/Materials and Manufacturing Directorate (ML) and the AFRL/Air Vehicles Directorate (VA). The ITTP and directorate staffs participate in the processes described above to develop the S&T program each year along the same time line used by the ASC to develop the PE 6.5 acquisition program.

All of these processes are timed so customer requirements can be updated by the beginning of the calendar year. According to the schedule, requirements-driven program recommendations are developed during the spring, leadership approval processes are completed, and budgets are finished by early summer in time to begin implementation at the beginning of the fiscal year in October.

Program Strategy and Road Maps

The Air Force technology strategy for managing the aging aircraft fleet is shown in Figure 2-2. The warfighters that manage the aircraft have a formal plan for keeping the structure healthy, the Force Structural Maintenance Plan (FSMP), which specifies what must be done to the aircraft structure during maintenance and how it must be maintained when returned to service.

Road maps for resource allocation are developed for each technical topic area. The road maps, along with a high-level strategy, summarize the funding of AFRL and ASC programs, the program interrelationships, key program milestones, and scheduled product deliveries to the warfighter and sustainer customers. The principal interface between the supplier and customers occurs through the FSMP, which is used to guide aircraft maintenance and the development of structural-assessment tool sets by the technology community. The structural-assessment tool sets include structural integrity analysis techniques and supporting technologies for the prevention, identification, repair, and maintenance of structural degradation caused by cracking and corrosion. Cost-effectiveness analyses are being incorporated into the tool sets.

The Air Force envisions that the implementation of new technologies will lead to a cultural change in the sustainment philosophy for aging aircraft. Instead

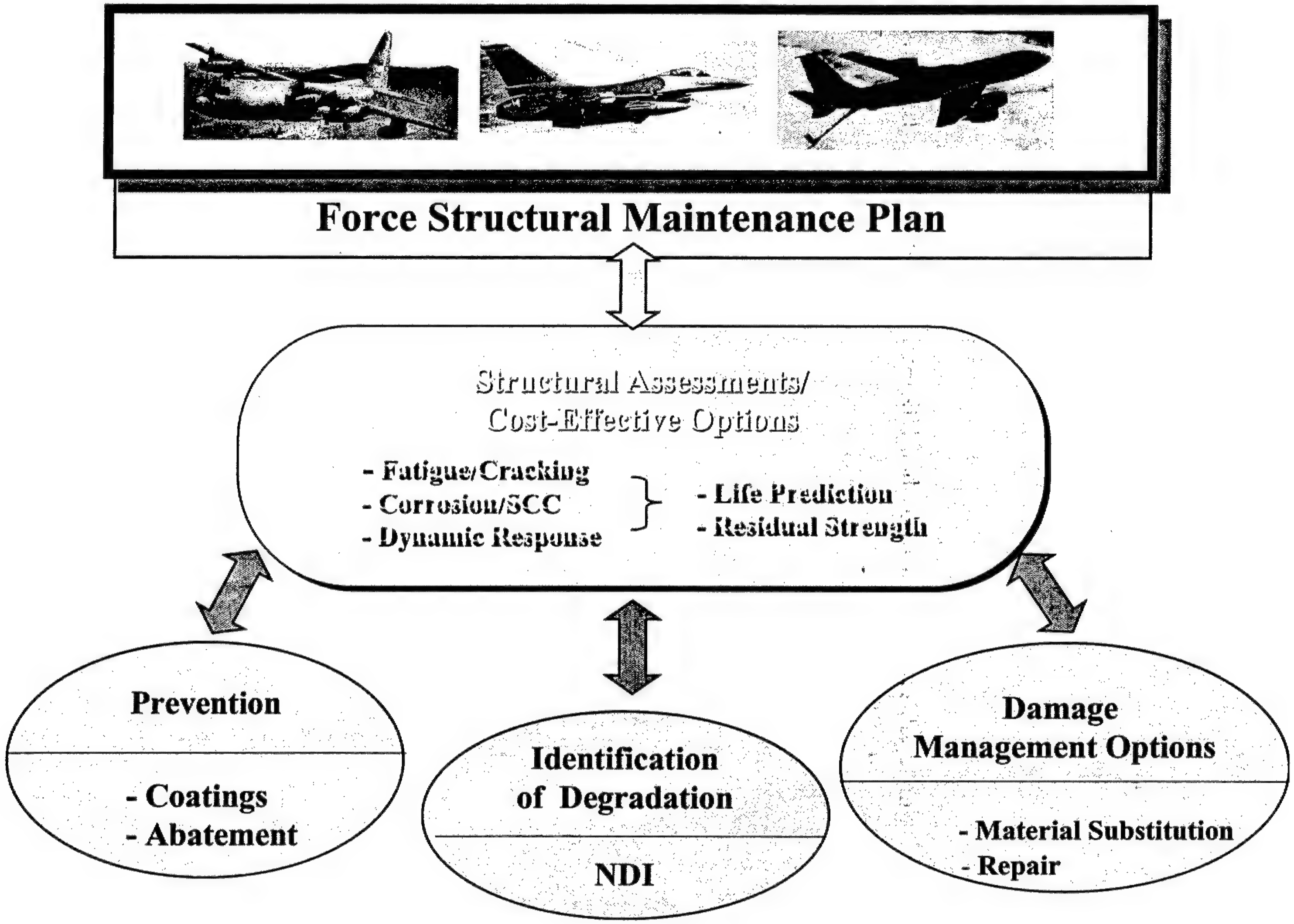


FIGURE 2-2 Strategy for managing the aging aircraft fleet. Figure courtesy of Air Force Aeronautical Systems Center.

of the old find-and-fix culture, which is conservative, reactive, and often costly, the new culture will incorporate a proactive philosophy of anticipating and managing problems. This new culture is much like the prevention-and-control strategy that has been very effectively implemented by the commercial aircraft industry. The new culture will enable the Air Force to anticipate and correct problems and manage its workload more effectively.

The major needs identified by AAAT are as follows:

- developing economic-service-life and cost-of-ownership models
- determining the onset of widespread fatigue damage
- preventing, assessing, and controlling corrosion
- reducing the inspection burden and improving inspection capability
- standardizing bonded repair
- improving maintenance business practices

The ASC Aging Aircraft Product Support Group has programs in all of these areas. Since 1996, these programs have been the principal source of new resources. ASC programs funded for FY01 are shown in Table 2-1 in order of priority. Note that some PE 6.5 programming is being initiated in high-priority subsystems areas such as electrical wiring and landing gear.

Future programs may focus on NDE/NDI, repair, corrosion control, and structural integrity (see Table 2-2). As Tables 2-1 and 2-2 show, corrosion (prediction, detection, and control), repair, and NDE/NDI are, and will continue to be, major areas of emphasis for aging aircraft. Tables 2-1 and 2-2 also indicate many opportunities for SBIR projects.

SBIR programs are currently not emphasized on road maps for future research (or in the programming strategy these road maps represent). One reason for this is that engineers cannot count on being awarded a Phase I topic when it is needed. Even if they are awarded one, there is no certainty that a Phase II award will be made following a successful Phase I. Many engineers attribute the problem to the large number of topics that are submitted initially to higher levels for approval, the very low percentage actually approved, and the lack of full-SBIR-cycle resource commitments.

Finding. The current planning process does not encourage the identification of the SBIR program on the road map; thus, many Air Force engineers do not see the SBIR program as an opportunity to address issues in a timely fashion.

TABLE 2-1 FY01 ASC Aging Aircraft Acquisition Programs

1. Corrosion quantification for structural integrity analysis
2. Detection and quantification of hidden corrosion using ultra-image system
3. Corrosion prediction management
4. AGILE for new landing-gear technologies
5. MAUS ultrasound eddy current wing-skin corrosion detect transition
6. Improvement of wire system integrity for legacy aircraft
7. Quality control of composite/bonded repair surface preparation
8. Material substitution for aging systems
9. 2nd layer inspection of F-15 lower wing-spar areas
10. AGILE for brake system and overhaul process improvement
11. Aging aircraft software library
12. Exfoliation effects on buckling strength
13. Wiring maintenance data analyses

Table courtesy of Air Force Aeronautical Systems Center.

TABLE 2-2 Future Technology Programs

Nondestructive investigation (NDI)	Corrosion-focused tools Multilayer inspection Hidden damage Health monitoring NDI through paint
Repair	Smart patch repair Advanced mechanical repairs Composite patch total transition
Corrosion control/suppression technologies	Surface preparation for field/depot Materials substitution Cadmium/chromium replacement Corrosion prediction/structural integrity modeling Paint-for-life corrosion system Selective stripping Piece part counting/repair technologies
Structural integrity	Add corrosion prediction to the structural integrity code Affordability framework

Table courtesy of Air Force Aeronautical Systems Center.

Recommendation. Under the current funding process for SBIR, at least one contract can be funded for each topic. These agency-approved and laboratory-approved SBIR topics should be shown on road maps systemwide and should be built into the overall road map programming strategy.

If the focus topics approach (described in Chapter 5) is implemented, SBIR funding used to support the development of innovations needed can be accorded attention when a new research or development focus is being planned or is just beginning.

Resources

The AFRL baseline funding for R&D on aging aircraft includes funding for projects focused on structural integrity, repair, NDE/NDI, and corrosion. Table 2-3 shows the funding profiles for those four areas from FY99 through FY05. ASC funding for the new PE 6.5 acquisition program in aging aircraft managed by SMA is shown in Table 2-4.

TABLE 2-3 AFRL Funding Profiles for Aging Aircraft Programs (million $)

	FY99	FY00	FY01	FY02	FY03	FY04	FY05
Structural integrity	8.5	11.0	9.3	13.3	16.4	12.7	11.5
Repair	4.2	5.0	5.0	3.7	1.6	0.2	0.2
NDE/NDI	3.6	2.8	1.8	2.5	3.5	1.7	0.7
Corrosion	5.5	2.9	1.6	1.5	1.4	1.4	1.5
TOTAL	21.8	21.7	17.7	21.0	22.9	16.0	13.9

Table courtesy of Air Force Aeronautical Systems Center.

TABLE 2-4 ASC Funding for Aging Aircraft (million $)

	FY99	FY00	FY01	FY02	FY03	FY04	FY05
Approximate PE 6.5 funding	4.6	4.9	14.2	28.2	42.1	42.9	43.7

Source: Defense Technology Information Center, <www.dtic.mil/rdds/>.

Other acquisition programs managed by ASC/SMA also have aging aircraft programs (see Table 2-1). These include the Commercial Operations and Support Savings Initiative, a DOD initiative for the insertion of cost-saving commercial technologies into fielded military systems; overall funding for this initiative is projected to be approximately $20 million per year through FY05. ASC's Productivity/Reliability/Availability/Maintainability Program also includes work on structures to facilitate the transition of off-the-shelf and emerging technologies; funding is projected to increase from $9.4 million in FY00 to $31.2 million in FY05. These significant funds are an important potential source of Phase III funding for SBIR innovations.

An AFRL-directed analysis of the technology recommendations in the 1997 NRC report indicated that additional S&T investments would be appropriate, particularly in the areas of NDE/NDI and corrosion. The results of this analysis are shown in Table 2-2. AFRL did not increase its overall investments significantly; however, investments were focused in the areas recommended by the NRC (NRC, 1997) and the AATT.

TECHNICAL ISSUES

The 1997 NRC report described many technical challenges involved in maintaining a large fleet of aging aircraft; in this section, those technical challenges are summarized and areas that can be addressed by the SBIR program are identified. This section also provides (1) background on other technical issues facing the Air Force and (2) a description of some R&D undertaken in response to recommendations in the 1997 NRC report.

Key technical issues are listed below (NRC, 1997; Lincoln, 2000):

- adequacy of damage-tolerance derived NDI programs
- determination of the time of onset of widespread fatigue damage (WFD)
- prevention and tracking of corrosion and incorporation of the effects of corrosion into structural integrity analyses
- high-reliability repairs
- adequacy, completeness, and retention of flight data and field and depot maintenance information
- flight beyond design life
- ability to make repair, replacement, and retirement decisions: support of cost-of-ownership and economic-service-life determinations

These issues, and the issue of structural dynamics and aeroelasticity, are discussed below.

Fatigue and Corrosion Fatigue

Air Force Structural Integrity Program

ASIP has developed a successful cradle-to-grave approach to ensuring the durability and safety (damage tolerance) of aircraft structures. In this damage-tolerance approach, a severe defect, flaw, or crack is placed at several critical locations in the structure where, if failure were to occur, loss of the aircraft might result. Crack-growth calculations, combined with known NDE/NDI high-probability-of-detection (POD) limits, are used to determine inspection intervals and the safety limits of the structure. Durability of an aircraft is established by assuming typical flight and structural conditions. The prediction of fatigue life is based on the identification of critical locations; definitions of structural loads, stresses, and stress spectra; the quality of the structure's manufacture; and the determination of crack growth as a function of the number of loading cycles for various mission profiles (see Figure 2-3). This information is then used in the development of the FSMP.

The procedure for handling the structural integrity of aircraft structures is described in the 1997 NRC report, which also references the detailed military standards that are followed. Damage-tolerance assessments are the basis for maintaining flight safety. The basic principle of ASIP is that the damage-tolerance approach, in conjunction with a robust inspection and maintenance program, ensures flight safety. The current process, as institutionalized through ASIP, is working well.

The 1997 NRC report also provides research recommendations for low-cycle and high-cycle fatigue. Two technical issues are related to low-cycle fatigue:

- the rapid increase in the number of fatigue-critical areas in safe-crack-growth-designed structures (structures designed to allow cracks that do not compromise safety) and the potential for missing new areas as they develop
- the onset of WFD in fail-safe-designed structures

The committee that produced the 1997 NRC report concluded that it could not develop a research initiative that would improve on the current approach for identifying new fatigue-critical areas. Therefore, the Air Force has no current or ongoing research in this area. R&D in low-cycle fatigue is focused on WFD. R&D on high-cycle fatigue falls under the category of structural dynamics and aeroelasticity, described below.

Much of the WFD in aging aircraft occurs in joints, where it is caused mostly by friction and wear associated with joint contact loads. These stresses are

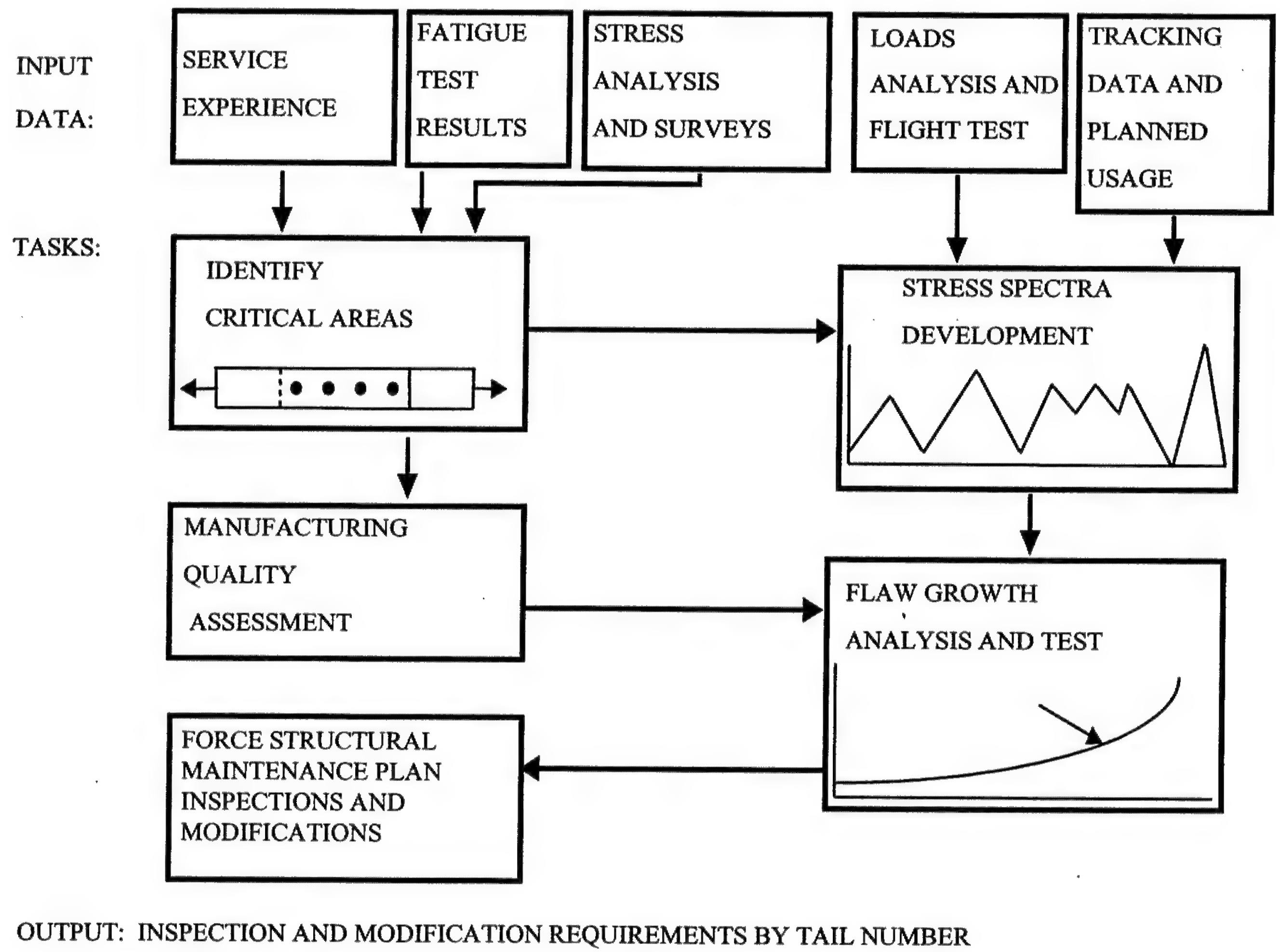


FIGURE 2-3 Damage-tolerance approach to the prediction of fatigue life. Figure courtesy of Air Force Aeronautical Systems Center.

important to the onset of WFD characterized by the simultaneous presence of small cracks in multiple structural details. The onset of WFD, which is the life-limiting condition, is defined as the simultaneous presence of small cracks in multiple structural details; when the cracks are of sufficient size and density, the structure can no longer sustain the required residual strength load in the event of a primary load-path failure or a large partial damage incident. When the onset of WFD occurs, the airframe has reached its operational life limit. However, the life of the aircraft can sometimes be extended if parts can be changed.

The development of cracking in joints has long been associated with fretting, which is defined as small-scale, relative sliding motions that occur between contacting surfaces. Fretting and associated concentrated stresses are known to lead to fatigue of joints and could well be a mechanism for the onset of WFD. In lap joints, fretting fatigue can lead to cracking at the rivet-skin interface and at the skin-skin interface, known as the faying surface (Szolwinski et al., 2000).

Recently, several investigators showed that conventional mechanics-based models of fatigue can be used to model fretting fatigue. Thus, the wealth of fracture mechanics technology that has been developed as part of ASIP can be applied directly to predicting the effects of WFD on residual strength. This R&D has been supported by the Air Force both as part of its aging aircraft programs and as high-cycle fatigue initiatives, primarily associated with aircraft engines.

Newman and Piascik (2000) used a mechanics-based fatigue modeling of fretting of joints based on the notion of using equivalent initial-flaw size (EIFS) to predict the initial damage. Thus, fatigue-growth models could be used to predict fatigue lives for lap joints. The EIFS is indeed comparable to that found in microstructural features characterized by microscopy.

The predictions described above rely on small-crack theory and predictions of total life based on back calculation of the EIFS for life data. The most promising analytical approach is to use EIFSs based on experimental data. The 1997 NRC report suggested that an EIFS database, correlated with full-scale structural test articles, be developed for cracks that initiate because of fretting, very small defects, scratches, dings, and corrosion damage. AFRL and NASA continue to work on this problem through testing and inspection of full-scale test articles of lap joints. SBIR could be used to develop full-scale, finite-element models that include the details of friction and accompanying stresses in joints in the fatigue-life calculations.

For the ASIP to accomplish this, it must have a robust means of calculating stresses once loads are known. Evaluations of primary sources of loads are described below in the section on structural dynamics and aeroelasticity. Many groups have all-encompassing, finite-element capabilities for calculating stresses. Primary tools for the implementation of stresses into structural integrity methodology are Air Force Grow (AFGROW, a software code) and NASGROW (developed by NASA). AFGROW is maintained and constantly upgraded by

AFRL to increase the accuracy of structural life assessments. AFGROW presently has the capability of analyzing multiple cracks at holes to assess WFD. SBIR could assist in the incorporation of finite-element results into AFGROW.

Corrosion Fatigue

The damage-tolerance approach to the prediction of fatigue life requires a definition of structural loads, the determination of critical stresses and their locations, and the determination of crack growth as a function of the number of loading cycles for various mission profiles (see Figure 2-3). Fracture mechanics has provided a theoretical framework for relating the crack growth rate, the increase in crack length per cycle, and the stress intensity factor. A major unresolved challenge is how to include the effects of corrosion in this theoretical framework for predicting fatigue life. Including corrosion effects will require both basic and applied R&D. SBIR efforts might incorporate present knowledge of corrosion effects into existing fracture-mechanics-based models for predicting fatigue life.

Both the AFRL and ASC aging aircraft programs are developing new capabilities for an improved structural integrity tool set (both for cracks and corrosion). The AATT has major programs in each of the corrosion fatigue building block areas shown in Figure 2-4. The AFRL Corrosion Fatigue Structural Demonstration Program and companion ASC Corrosion Management Program, the core efforts in the corrosion fatigue strategy, are focused on adding corrosion effects to the baseline structural integrity analyses that have been the basis for the ASIP durability and damage-tolerance approach (and championed by the current Air Force technical leader for aging aircraft, Jack Lincoln). A successful shift from the find-and-fix approach to a more cost-effective anticipate-and-manage approach will depend on the quality and completeness of the analysis tool sets.

The key implications of corrosion damage for structural life and residual strength are shown in Figure 2-5. Corrosion degradation occurs in many forms and can occur in many structural areas; often the critical areas are hidden. Even though NDE/NDI techniques being developed are sensitive enough to discriminate among the forms of corrosion and can provide some estimates of hidden damage, better technologies are critical. Shortfalls in high-POD inspection for small cracks and corrosion may mean that inspection intervals should be shortened (which would increase costs and could decrease aircraft availability). Another continuing challenge for the NDE/NDI community is the transitioning of improved, but more sophisticated, technologies to use in the field and at depots, which could take many years.

Once the best NDE/NDI information has been provided, the effects of the observed damage on strength and remaining life must be established. Before these

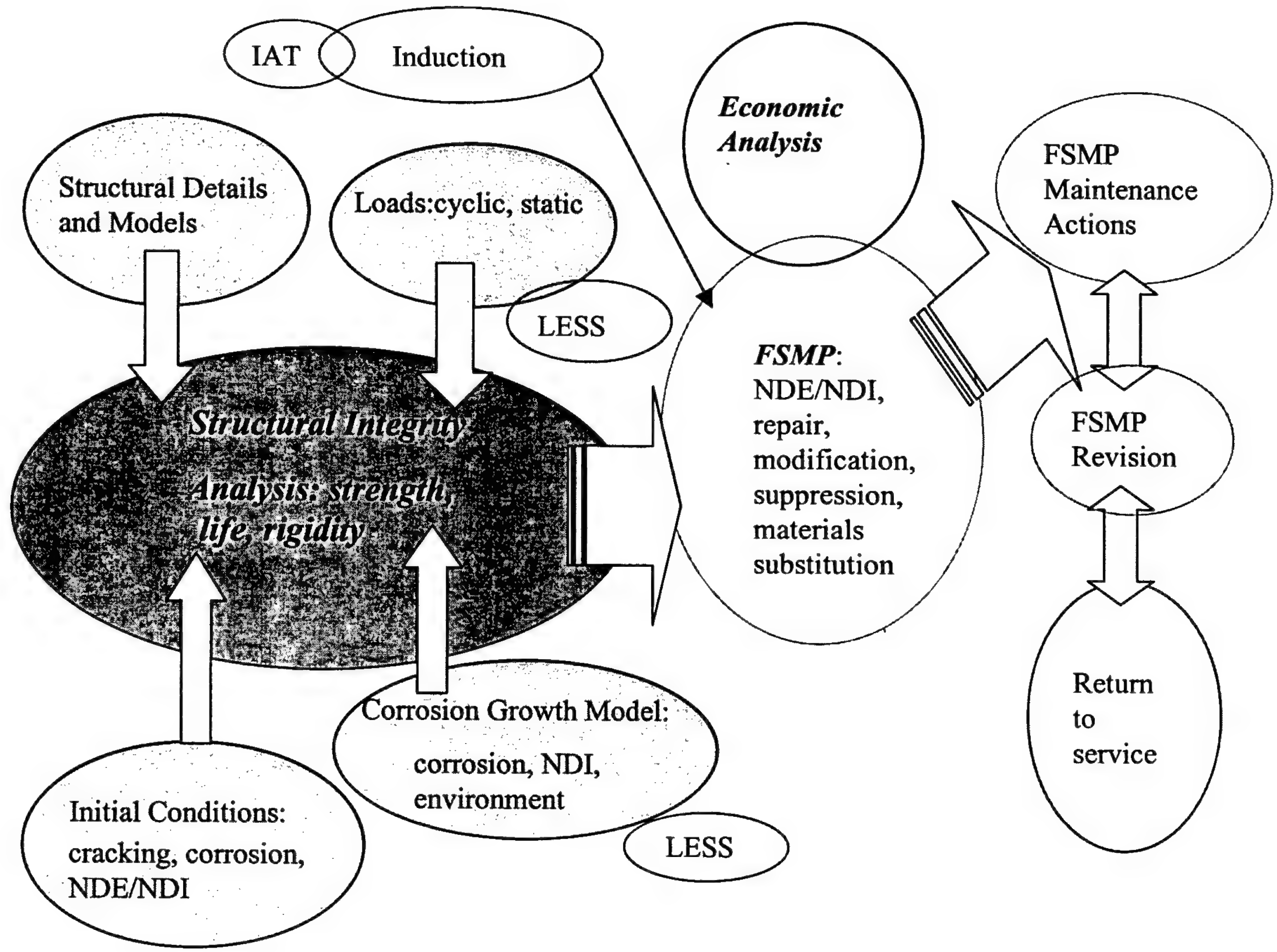


FIGURE 2-4 Management of structural damage in aging aircraft. Figure courtesy of Air Force Aeronautical Systems Center.

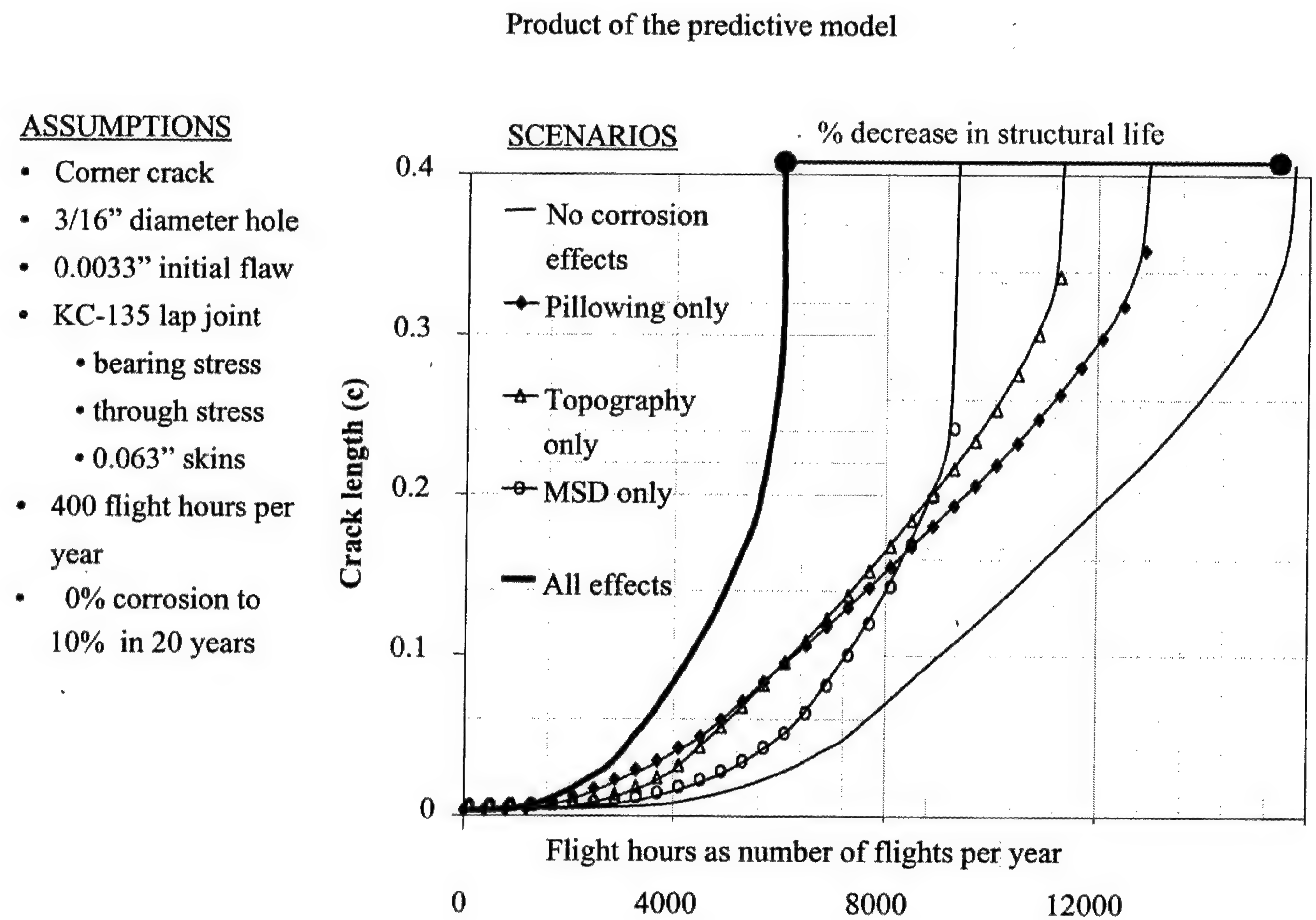


FIGURE 2-5 Corrosion fatigue structural demonstration approach. Figure courtesy of Air Force Aeronautical Systems Center.

correlations can be adopted by the ASIP, they must be validated, which usually requires full-scale testing. Even when reasonably accurate descriptions of corrosion phenomena have been incorporated into structural integrity analyses, a difficult additional challenge must still be met—a practical model describing the corrosion degradation as a function of time. The expected future deployment of the aircraft must also be factored in, so environmental severity index correlations can be introduced.

As corrosion models are developed, the scatter in the basic data is being continually scrutinized to guide improvements in correlations and to guide the development of more comprehensive NDE/NDI techniques. The practical successes of the durability and damage-tolerance approach for dealing with fatigue cracking have depended, at least in part, on the development of extensive databases with manageable scatter and uncertainty. This is still a challenge when corrosion degradation is involved.

The long-standing ASIP framework is sufficiently robust to accommodate new procedures. The inclusion of cost and economic features in the improved tool sets will be especially important. Gathering corrosion-degradation information, evaluating it, and taking appropriate actions could significantly increase the cost of aircraft tracking and maintenance. A key challenge will be to implement the anticipate-and-manage approach as cost effectively as possible. And corrosion prevention will continue to be a top priority area for Air Force aging aircraft S&T and acquisition programs. In the near term, the focus will be on completing the development of a first-generation tool set for corrosion-fatigue and structural-integrity analysis and training personnel to use it. Further development will be necessary, however. Given the complexity of corrosion phenomena generally and the current limitations of NDE/NDI technology to quantify corrosion degradation, especially when it is hidden from direct view, the first-generation tool set will have many empirical features.

Program Themes for the Future

Principal themes for the next-generation tool set and the longer term will include the following:

- the development of more complete corrosion growth rate models
- the development of improved NDE/NDI corrosion inspection techniques, especially for hidden corrosion, and the quantification of the effects of corrosion degradation on mechanical properties
- the incorporation of cost parameters into structural integrity tool sets
- the incorporation of new developments into multiple-phase, next-generation corrosion fatigue analysis tools

- the incorporation of cost-based, corrosion-fatigue analyses into SPO/MAJCOM cost-of-ownership and economic-service-life models

Structural Dynamics and Aeroelasticity

There are several sources of dynamic loads on an aircraft that can lead to crack propagation and fatigue failure. For transport aircraft and some bomber aircraft with large-span (high aspect ratio) flexible wings, the predominant loads may be the result of aerodynamic forces created by atmospheric turbulence or gusts, which often govern much of the structural design, from the standpoint of both maximum loads and loads leading to fatigue. For fighter aircraft, extreme maneuvers may be the most important factor in maximum stress conditions and in generating repeated loads that lead to fatigue. Some aircraft maneuvers may lead to qualitative and important changes in the aerodynamic flow field around the aircraft. For example, massive flow separation may occur (with or without accompanying shock-wave oscillations), and so-called buffet loads caused by the large-scale oscillating flow field may be induced and give rise to significant dynamic loads on the aircraft structure. Although engine structures per se are not treated in any detail in this report, similar considerations apply to them. For engines, the term "inlet distortions" rather than gusts is more often used. Indeed, the engine itself may induce significant acoustic loads on the airframe structure. Acoustically induced fatigue has occurred in the B-1 horizontal tail, and buffet-load-induced damage has occurred in the F-15 and F-18A vertical tails. Collectively, these oscillations and the resulting structural failures are called high-cycle fatigue.

As the 1997 NRC report noted (p. 32),

> The committee believes that dynamic loading and the resulting high-cycle fatigue is a key aging aircraft issue as well as an initial design issue, particularly for high-performance combat aircraft. The key technical issues include:
>
> - identification, reduction, or elimination of sources of dynamic excitation
> - passive and active methods to reduce the response of aircraft structures
> - measurement and characterization of the threshold for fatigue propagation values for airframe materials, including the applicability of long crack thresholds to small crack behavior
> - in-flight monitoring of changes in dynamic behavior.

The first two issues are discussed next.

One effective approach to delaying, diminishing, or eliminating structural damage is to reduce the dynamic aerodynamic loads or the dynamic structural

response of the aircraft. The loads may be diminished by using active or passive control devices. For passive control, various damping enhancements have been proposed. Both constrained-layer damping, in which a viscoelastic material is constrained between two elastic layers (usually one of them is the primary structure whose response is to be reduced), and dry-friction damping have been proposed. Devises for the latter include the so-called shroud dampers, which contact adjacent fan blades in a jet engine. Dry-friction devices have not been used in airframes, although there is some evidence that damping due to dry friction is an important, though unintended, consequence of traditional metal airframe construction.

Although not always recognized by structural designers, the aerodynamic flow that gives rise to the excitation of the structure can also contribute restoring forces, including damping, to the structure. That is, the structural response changes the aerodynamic forces on the structure, giving rise to aerodynamic damping. It is well known that the aerodynamic forces caused by structural motion can lead to a dynamic instability called "flutter" when the damping in an aeroelastic mode sinks to zero at some critical flight speed, the flutter speed. (An aeroelastic mode is a dynamic mode that represents a coupled oscillation of the structure and surrounding aerodynamic flow.) It is also true that for flight velocities below the flutter speed (at which aircraft are designed to fly), these aerodynamic forces may provide a damping to the structure that exceeds that damping inherent in the structural material or configuration, or both.

A recent observation of aeroelastic dynamic loading phenomena in operational aircraft (the B-2, the F-16, and the F-18) is that of limit cycle oscillations. Although these are thought to occur as a result of an interaction between the structural motion and the induced aerodynamic forces, the specific physical mechanism is not yet well understood and is a subject of current PE 6.1 and PE 6.2 research. The nature of limit cycle oscillations is that the motion is bounded in amplitude and is often a near-sinusoidal motion of nearly fixed peak amplitude and dominated by a single frequency. Although this motion is not immediately catastrophic (as is the classical flutter oscillation), a limit cycle oscillation can lead to structural damage and, potentially, to fatigue failure.

Another approach to reducing structural response is through active control devices. An early successful demonstration of this technology was in a B-52 aircraft in which a reduction of gust response was achieved. In this and many early efforts, the motion of the aircraft was sensed and an existing aerodynamic control surface was driven in response to the sensed motion. This feedback loop was shaped to achieve the desired reduction in aircraft motion and structural loads. In recent years, the research community has turned its attention to so-called smart structures, which have smaller, localized sensing and controlling elements made of (for example) piezoelectric materials. A demonstration of this technology on full-scale vehicle structures is currently being attempted. A combination of smart

materials and more traditional control actuators may prove to be an effective way of reducing structural response.

The greatest benefits can be derived from active and passive control devices incorporated into the structural design process as part of the initial aircraft design. Nevertheless, active or passive damping and control devices may also be attractive for modifying existing aircraft. For example, a damping device was used to modify F-15 aircraft to reduce dynamic response due to buffeting.

As the 1997 NRC report also noted, "Near-term research opportunities include efforts to improve methods to determine dynamic response" (p. 52). This committee agrees but notes that improvements in the computational efficiency of mathematical models for time-dependent or unsteady aerodynamic flow fields that accurately describe the dynamic fluid forces acting on the aircraft structure will require both near-term and long-term R&D. Promising advances have been made recently in reduced-order modeling of unsteady aerodynamic flow fields. This model uses a global, modal description of the flow field rather than a local description as in traditional computational fluid dynamics models based on finite differences or finite elements.

The 1997 NRC report recommended the development of "load monitoring and alleviation technologies that take advantage of recent advances in sensors and controls and computational capabilities" (p. 53). This committee heartily concurs with that recommendation and with the observation that intelligent control systems have been developed and demonstrated to suppress flutter and buffet load using both conventional control surface actuators and piezoelectric actuators.

Another recommendation of the 1997 report with which this committee concurs is that "long-term research be conducted to develop improved damping material systems that provide low-temperature damping performance and better resistance to aircraft fluids and environmental exposure" (p. 72). In this regard, dry-friction damping induced by adjacent sliding structures merits further investigation and exploitation in airframe systems.

It has been suggested that impact damage due to discrete sources, such as landing loads or bird strikes, is often a more critical design condition for composite structures than fatigue induced by crack propagation (NRC, 1996). Improved modeling and measurement of structural damage due to impact loads offer attractive opportunities for near-term and long-term R&D to predict and reduce structural response using modern computational and experimental methodologies.

Opportunities for SBIR-funded projects in this area of technology include active control to reduced dynamic loads and response, smart structural concepts to monitor and shape dynamic response, and improved computer modeling and prediction of aerodynamic and structural loads to more accurately estimate fatigue life, time between inspection cycles, effectiveness of active control devices, and smart structural elements.

Corrosion

Corrosion of airframe structures has been identified as the most costly maintenance problem for Air Force aging aircraft (SAB, 1994), and these costs are rising steadily (Cooke et al., 1998). The Air Force Scientific Advisory Board Materials Degradation Panel cited estimates of the costs associated with corrosion-related detection and repair in the range of $1 billion to $3 billion per year (SAB, 1996). Corrosion occurs in many forms, most of which are routinely detected in aging aircraft. Forms of corrosion are typically divided into general or uniform attacks and localized attacks, such as pitting, crevice corrosion, intergranular corrosion (including exfoliation), galvanic (two-metal) corrosion, de-alloying (selective leaching), hydrogen attack, erosion-corrosion, and stress-corrosion cracking (SCC).

Corrosion of aging aircraft results from a combination of the following factors:

- older aluminum alloys and tempers that are more susceptible to corrosion than currently available alternatives
- inadequacy or degradation of corrosion-protection systems
- exposure to corrosive environments, such as humid air, saltwater, sump-tank water, and latrine leakage

Despite best practices of prevention and control, total elimination of corrosion is virtually impossible. Corrosion control in aging aircraft requires effective prevention, detection, and repair practices. The corrosion protection and control systems of aging airframes deteriorate over time. Consequently, maintenance costs increase as corrosion is identified and repaired. Based on current experience, the practice of repairing corrosion damage identified by visual inspection has seemed adequate for maintaining the integrity of aging structures. Unfortunately, a substantial amount of corrosion damage sustained by older Air Force aircraft is hidden from direct view; thus, a significant amount of material degradation can remain undetected. More importantly, the extent and severity of corrosion damage in similar aircraft can vary widely because of differences in mission cycle, environmental exposures, and the extent and type of maintenance.

Different forms of corrosion (i.e., corrosion caused by different mechanisms) exhibit different characteristics and consequences. For example, exfoliation corrosion (severe intergranular corrosion in which the buildup of corrosion causes flaking and surface blisters) and pitting can typically be readily detected, depending on the accessibility of the damaged surface. Although these two forms of localized corrosion are evident as surface deterioration, they may not be found if the surface is inaccessible to visual inspection. Moreover, intergranular corrosion that propagates along grain boundaries oriented away from exposed

surfaces may be indistinguishable from the surface, challenging the reliability of NDI techniques (Mindlin et al., 1996). Crevice corrosion, which occurs in lap joints, is particularly insidious because significant material loss can remain undetected. Such unexpected corrosion damage increases maintenance costs and time in the depot for maintenance. A more critical consequence is the increased risk that corrosion, in the presence of other forms of damage (e.g., fatigue), may cause a significant decrease in damage tolerance.

Although corrosion is very costly to repair, it has not yet been identified as the cause of any of the structural failures that have resulted in the loss of an Air Force aircraft. This is because it has been detected and repaired before becoming a flight safety problem. However, the Air Force admittedly has historically treated corrosion with a find-and-fix approach rather than an anticipate-and-manage approach. Current Air Force corrosion prevention and control programs are designed to change the culture so that corrosion is controlled using the latter rather than the former approach. Most notable among these programs is a PE 6.5 program, Corrosion Prediction Management, which is managed at the AFRL.

Corrosion prevention should begin during the acquisition stage with the selection of appropriate materials and manufacturing processes. The commercial aircraft industry has developed, as part of its structural maintenance programs, provisions to upgrade corrosion resistance through the use of substitute materials and heat treatments; improved protective finishes and corrosion prevention compounds (CPCs); and design features such as drainage and sealing to prevent corrosion. For example, the high-strength aluminum alloy 7075 has been replaced in many forging applications by the more corrosion-resistant alloys 7050, 7150, and 7055. These alternative alloys have been downselected based on studies such as the current PE 6.5 AFRL program, Material Substitution for Aging Aircraft. Similarly, the stress-corrosion-resistant and exfoliation-resistant T-7x tempers are now used for 7xxx-series aluminum alloys instead of the original design T-6x tempers, which have repeatedly shown inferior resistance to corrosion and SCC. The AFRL's recently developed retrogression and re-aging heat treatment is under study as a means for increasing corrosion resistance while maintaining the strength of existing 7075 components, the replacement of which would be costly. This two-stage technique, currently under development using a ZIMAC heating system, would locally boost corrosion resistance without sacrificing strength. Details of this heat treatment and its advantages can be accessed in a recent report, *Stress Corrosion Cracking in Aging Aircraft* (Shah et al., 1999). Similar engineering guidelines on substitute materials and processes with corrosion resistance better than those used in the original design have not yet been formally developed for Air Force aircraft.

To avoid costly component repair and replacement, much more emphasis should be given to early detection of corrosion and the implementation of

effective corrosion control and prevention practices. The 1997 NRC report identified, for example, the most important operations needs:

- environmentally compatible protective coatings to replace the hazardous materials being phased out (e.g., chromates)
- generalized use of CPCs that can be applied on external surfaces and that will penetrate and protect unsealed joints and around fasteners
- guidance for the application of upgraded alloys and processes offering improved corrosion protection
- improved NDE/NDI techniques to reveal and estimate hidden corrosion without requiring disassembly of the aircraft
- classification of corrosion severity, similar to current commercial aircraft practice, to provide guidance for maintenance

Detection of corrosion is necessary for assessing the damage tolerance of affected structures and taking appropriate corrective actions. Current inspection methods require component disassembly, which increases the probability of maintenance-induced damage. Accurate detection and quantification of corrosion under paint, under multiple layers, under fastener heads, and on the interior surfaces of built-up structures would ensure that required repairs are made.

Stress Corrosion Cracking

SCC is treated separately from other forms of corrosion because of its potential structural effects on aging Air Force aircraft. Some unique aspects of SCC render it much more dangerous than other forms of corrosion. SCC is an environmentally induced, sustained-stress (versus cyclic-stress) cracking mechanism that requires three components: (1) a susceptible microstructure; (2) a corrosive environment; and (3) local tensile stresses. Prevention requires elimination of any of these components. SCC, characteristically intergranular in aging aircraft environments, can occur with little or no evidence of corrosion products and is therefore often difficult to detect visually. SCC can also occur transgranularly in some material systems (most notably in steels, but also in aluminum alloys).

SCC is typically exacerbated by residual tensile stresses remaining from material heat treatment or component fit-up but can also be triggered by operational loads and forces from the buildup of corrosion by-products that act as wedges to open cracks. The poorer mechanical properties of forging and thick plate materials in the short-transverse-grain direction compared with those in the longitudinal-grain direction have been well documented, so structural components are designed for the primary load paths to be parallel to the principal grain

direction. In this case, the elongated grain boundaries are parallel to, rather than normal to, the applied operational stresses. Fortunately, when SCC occurs parallel to applied operational stresses, cracks can often be very large (as much as several inches long) before they become a flight safety problem. Conversely, loading stresses parallel to the short-transverse direction of a plate or extrusion, where the grain boundary density is far greater than that of either the rolling or long-transverse directions, result in a highly increased sensitivity to SCC.

Grain orientation with respect to the applied flight stresses has, in general, not caused flight safety problems, but this may not always be the case. If large in-plane stress corrosion cracks or delaminations go undetected, they could cause a loss in shear strength and trigger failure modes other than the tensile mode normally associated with crack propagation. In addition, in thick sections (e.g., complex machined fittings) where there may be irregular grain flow and three-dimensionally applied stresses, it is often difficult to predict if a stress-corrosion crack will turn normal to the largest component of stress and result in a tensile fracture.

The costly replacement and repair of components necessitated by SCC could be reduced, or at least delayed, with appropriate maintenance. For example, improved CPCs and surface finishes would reduce the corrosion rates of susceptible materials; manufacturing processes could be modified to reduce exposed end-grain and residual stress effects that exacerbate SCC in large structural components; and repair procedures could be improved to maintain the integrity of the surface finishes. Programs such as these could be funded through SBIR.

In addition to preventive maintenance, the onset of SCC should be anticipated using statistical tools to predict the time to initiation of the cracks and their growth rates. Current NDE/NDI techniques, which are effective in the detection of surface-connected SCC, could be improved to detect cracks below coatings. A probabilistic approach, based on an evaluation matrix that includes factors, such as (1) material, (2) stresses and load, (3) manufacturing, (4) environment, and (5) surface finishes, has been developed and reported (Shah et al., 1999). Prediction of the onset of cracks would then be a complement to damage-tolerance analyses, which do not currently predict the occurrence of SCC. With continued and consistent improvements in prevention and control procedures, upgrading of susceptible materials with more corrosion-resistant alloys, and minimization of residual stress, SCC problems in aging Air Force aircraft should remain manageable and need not be a life-limiting damage mechanism.

Coatings

Coatings are an obvious operational requirement for implementing a cost-effective strategy to prevent and control corrosion damage to airframe structures. The integrity and durability of protective finish systems on aging aircraft is an important factor in corrosion prevention. Aircraft coatings must meet demanding design criteria, including ambient curing; adhesion to a wide variety of substrates; long-term corrosion protection against humidity, chemicals (e.g., hydraulic fluids, fuels, and solvents), and cleaning solutions; and mechanical durability under operating stresses and in fretting environments. Restoring coating integrity after maintenance and repair is extremely important.

CPCs that can be applied to external surfaces to penetrate and protect unsealed joints and around fastener heads would be very beneficial. These compounds, which are a critical part of maintenance programs to prevent and control corrosion, are being increasingly used in new aircraft, especially in lower fuselage areas. As an aircraft ages and protective finishes and coatings break down, the danger of part failures caused by SCC increases, particularly in structures not designed to be fail-safe. The epoxy and polyurethane systems that have been the mainstay of aircraft coatings have been modified and will continue to change in response to environmental regulations that limit the release of volatile organic compounds (VOCs) and materials containing heavy metals such as chromium or cadmium, used to inhibit corrosion. Specific technical issues have been identified for CPC development: (1) the need for a topcoat with good optical properties (e.g. high pigmentation) and superior durability; (2) the need for a primer that is both a good inhibitor and a chromate-free barrier to corrosion; and (3) the need for a surface treatment that can densify the surface oxide, thus providing corrosion protection without adding chromates.

A variety of coating technology programs are ongoing at the AFRL focused on near-term, medium-term, and long-term corrosion-prevention goals. The near-term programs are addressing the integration and transition of new coating materials and processes. Medium-term projects are focused on the development of high-durability, environmentally compliant (chromate-free and reduced VOCs) topcoats and selective stripping to the permanent chromated primer. Based on the promising results of current programs, the focus of long-term R&D has shifted toward discovering fundamental corrosion and degradation mechanisms. Many projects, such as the development of a permanent (30- to 40-year) primer or foundation layer, an 8-year mission-tailored topcoat that is easily removable, and effective NDE/NDI through coatings, have been established with the goal of minimizing maintenance over the system lifetime.

Nondestructive Evaluation Methods

For a fleet that is growing older and older and requires not only aircraft safety but also mission readiness, improved nondestructive inspection (NDI) methods are critical. As reported recently in the *Nondestructive Testing Information Analysis Center Newsletter*, "the reality of trying to maintain aircraft airworthiness over an unprecedented 50- to 80-year life span presents a whole new set of technical problems/issues the original design did not have to meet" (Bartel, 2000).

In concurrence with the 1997 NRC report, the AATT identified the detection of subsurface cracks and hidden corrosion as the two greatest concerns for deployed aircraft. The costs of repair for corrosion-related problems as estimated by the Air Force corrosion office survey (conducted periodically) exceeded $800 million in 1997 (Cooke et al., 1998). Not surprisingly, the critical nature of these two problem areas was overwhelmingly reinforced by operations and sustainment data from the Navy, as reported to the Joint Aeronautical Commanders Group. Accordingly, the DOD NDE/NDI community has focused its efforts on developing and implementing technologies to address these specific issues. Both the Air Force and the Navy have increased their use of SBIR funds to supplement their in-house efforts; however, those efforts have not yet made an impact at the field depot level.

The FAA, which is primarily a regulatory agency, has focused more on validating and enforcing the implementation of existing inspection protocols and improving the training of airworthiness inspectors and maintenance technicians for commercial aircraft. Although method development is not a specific aspect of the FAA's mission, the agency is supporting the development of maturing NDE/NDI technologies for corrosion and crack detection through its SBIR program. It is also encouraging commercial airlines and aircraft manufacturers to find alternative, less costly ways to perform required inspections. However, the FAA's major focus at the moment is on the detection of aging and faulty wiring.

Historically, the most common NDI method for detecting corrosion and cracking in aircraft structures has been visual inspection. Several drawbacks to this approach have been noted, the most significant being the amount of time it takes to inspect an entire airframe and all of its critical components visually and the inability to see beneath paint and inaccessible areas. By the time hidden corrosion is detectable visually—usually because the buildup of corrosion products between layers results in a bulging external surface (pillowing)—the degree of damage is so great (10 percent or greater material loss) that repair or replacement are the only viable options. For critical substructures, inspection often requires the costly removal of overlying components, which has the potential for causing damage. Also, some forms of corrosion damage, such as SCC, are not readily detectable visually, even at an advanced stage.

Implementing proactive measures for aircraft sustainment (e.g., life-cycle management decisions to repair, replace, or fly-as-is and the establishment of inspection intervals) will require quantitative assessments of damage as opposed to simple damage or defect detection. Other traditional nondestructive methods and facilities (e.g., radiography, ultrasonics, eddy current) could be used to characterize hidden cracks and corrosion. The issue has most often not been the feasibility of the method but the practicality and the specifics of its implementation. Multilayer structures in particular can present immense difficulties to NDE/NDI methods, such as ultrasonics and thermal imaging. The form of the flaw, such as cracks under rivet heads, SCC, and pitting, can severely impact the efficacy of NDE/NDI methods. In addition, field depots responsible for aircraft inspection, maintenance, and repair are traditionally not as well outfitted or up to date as their production counterparts or research partners. Manual inspections and many portable units are tedious and potentially ineffective owing to human factors, such as fatigue, that arise simply because such a large area must be covered to do the job correctly. The difficulty of correcting this situation has been compounded by growing demands (i.e., increasing costs of corrosion repairs) on decreasing sustainment funds.

These deficiencies have long been recognized by the Air Force, which sponsored an NED/NDI program in 1992 to evaluate commercially available NDE/NDI alternatives (Alcott et al., 1993). To the surprise of many researchers at the time, the enhanced visual method was the most effective of the portable, field-level methods surveyed for the detection of hidden corrosion. However, not all variations were represented in the study, and none of the techniques were performed at the levels desired by the Air Force. Most of the more advanced commercial equipment that had been successfully demonstrated in university or research laboratories was simply not field ready. In controlled experiments, these techniques were shown to be better in terms of sensitivity, but nonautomated field implementations were found to have the same drawbacks as existing techniques.

In addition to corrosion-detection solutions for large accessible areas, such as fuselage and wing skins, corrosion in lugs, fittings, and landing-gear components (some of the most dangerous corrosion), especially those made of high-strength steel where cracks can propagate from a single corrosion pit, must also be addressed. In a recent survey on Boeing's 7XX series airplane models, fittings accounted for 45 percent of safety-critical Airworthiness Directive inspection procedures. Current technology-ready programs using the Mobile Automated Ultrasound System (MAUS) scanner can already scan fuselage and wing skins and detect thinning to within 5 percent. But for corrosion in fittings, other solutions, such as ultrasonic modeling techniques, methods that can detect cracks beneath bushings, embedded sensors, and small rotating scanners for areas with poor access, will be necessary. Emphasis should be on low-tech, inexpensive methods

of inspecting small areas rather than on the development of expensive, complex systems built for a single purpose.

In spite of a growing number of candidate techniques and adaptations, the number of new techniques implemented has not met growing needs. Although additional improvements or adaptations of existing systems are being made, no catchall solution is waiting in the wings. Air Force-funded systems, such as the MAUS, have helped overcome many of the implementation difficulties (AFRL, 1998). With continued improvements in hardware and software design, MAUS has become more useful at the depot level, and, with the incorporation of eddy-current sensors, a complementary inspection method particularly sensitive to near-surface cracks, MAUS can take advantage of the automated scanning platform. Current R&D on pulsed or low-frequency eddy-current methods is focusing on making them more effective for detecting cracks in multilayer structures (Buynak, 2000; Smith, 2000). For some applications, neural networks have been shown to increase the POD thresholds for traditional ultrasonics (Mullis et al., 2000). Many other adaptations of inspection methods (e.g., thermal imaging and real-time radiography) with varying degrees of promise and maturity are being investigated. All of these projects are moving in the right direction, but not at a pace that would meet the needs of the aging aircraft sustainment community. A strong SBIR program in this arena could have significant early payoffs.

The 1997 NRC report recommended evaluation, validation, and implementation "of currently available NDE equipment and methods for use at Air Force maintenance facilities" as a near-term top priority (p. 64). The report also listed as a top priority the long-term need for the automation of successful inspection methods and the development of wide-area inspections. In addition, the report recommended a long-term top priority for an "integrated quantitative NDE capability," indicating that the detection sensitivity requirements (i.e., percent corrosion, crack length) should be derived from structural analyses, including corrosion and crack geometry and local airframe structures, and that the NDE methods must have consistent, reliable POD and flaw sizing.

The NDE/NDI development and insertion path the AFRL followed up to the time of the 1997 NRC report has since been validated by the report's findings. Although the Air Force technical community obviously agrees with the recommendations in the report, AFRL admits that it has insufficient funds and staff to address them. Although AFRL has not redirected funds to cover this gap, plans are being made to strengthen collaborations with the Navy and the Coast Guard and with federal agencies such as the Defense Logistics Agency, NASA, and FAA to take better advantage of SBIR funding. More proactively, the ASC aging aircraft program (PE 6.5), under the guidance of AATT, is stepping up to cover some of the NDE/NDI needs.

Nevertheless, the critical factor of time to technology insertion is not being met for several reasons. First, delays in getting SBIR-developed NDE/NDI

technologies to field level are partly attributable to a lack of bridging funds after Phase II. Second, communication with the aging aircraft end users (e.g. ALCs) is not being done early enough or with enough follow-on commitment. Therefore, end users are not aware of how long it takes (and how much it costs) for new devices to mature. Although SBIR funds represent a significant investment by the government, those funds alone are insufficient to bring a new technology through prototype development to near-term implementation.

Magneto-optic imaging of subsurface cracks, a new technology that resulted from SBIR funding, is a case in point (PRI R&D Corp, 1990). The current configuration of the imaging instrumentation is the result of two Phase I and Phase II R&D. In addition, the inventor required substantial venture capital, equivalent to about four more Phase I and Phase II funding cycles, to develop the instrument to its current state. It has been more than 10 years since the initial Phase I R&D, and no return on the investment has yet been realized. This time to commercialization is typical of most emerging technologies. Members of the committee have listened to several similar "success" stories in which the maturation of a new technology or concept took several cycles of SBIR Phase I and II funding to reach the technology insertion stage. Because small businesses must go back to the beginning of the SBIR process if Phase III funds or commercial partners cannot be found, they must contend not only with the delays associated with the Phase I and II selection and award processes but also with the possibility of not being selected in sequential cycles.

Although innovation is traditionally interpreted as a new device or method, the term also applies to a novel adaptation, implementation, or integration of an existing technique. Adaptations of existing technologies can be performed relatively quickly and thus are better suited to addressing immediate operational sustainment needs. Integration with an existing platform (such as eddy-current probes with the MAUS scanning system) can significantly reduce development time. But success requires the collaboration and commitment of the "owners" (manufacturer or user) of the existing technology. This often requires discussions and negotiations of intellectual property or licensing agreements, or both, with the government or a DOD subcontractor, an effort that many small businesses are not prepared to handle. More often than not, a small business chooses to pursue an independent path that requires more effort and time to reach the implementation stage. Therefore, encouraging integration and collaboration in Phase I and II SBIR programs could make a significant impact. Commitment by the Air Force to provide continued support for SBIR NDE/NDI developments is critical to successful bilateral partnerships.

Without a doubt, the development and validation of NDE/NDI methods for aging aircraft could benefit from SBIR programs, particularly those focused on implementation at the field depot level. Many new technologies and methods are

being developed that have the potential to solve many aging aircraft problems but that lack funding and support for their timely implementation.

Health Monitoring and Maintenance and Repair Issues

The area of health monitoring and maintenance and repair is also undergoing a change in philosophy from the reactive find-and-fix approach to a more proactive predict-and-manage approach. Regardless of the overarching philosophy, damaged airplanes will still have to be repaired. Repair of damage resulting from in-service degradation mechanisms, such as fatigue, SCC, corrosion (when thinning requires structural repair), and discrete source damage (e.g., foreign object impact, handling damage, lightning attachment), is a critical maintenance activity. Repair of aging aircraft can add in bolted or bonded reinforcement doublers over damaged areas or can replace damaged components, preferably with materials that are not as susceptible to deterioration, especially corrosion and SCC.

Health Monitoring

For the last 30 years, the ASIP has been dealing with fatigue cracking of aircraft structures. ASIP's key management activities have been the development of the FSMP and the Individual Aircraft-Tracking (IAT) program. However, as certain aircraft systems age—such as the KC-135, which is more than 40 years old—corrosion is becoming a major maintenance item, and significant sums of money are being spent on the detection and repair of corrosion damage. Consequently, future health monitoring should include the tracking of corrosion damage as well as fatigue damage. Developments in multifunctional chemical and physical sensors, microelectromechanical systems (MEMS), and smart diagnostics offer some hope that long-term research in onboard health monitors will be productive. In addition, alternatives to existing tape recorder systems should provide an acceptable return on investment, a significant improvement in data capture, improved turnaround time in reporting, the potential of integration with corrosion monitoring, faster identification of usage changes, and acceptance by the users.

IAT is intended to provide a limited amount of information on the flight loads experienced by all aircraft in the field. An Air Force goal is to tail-number-track every aircraft. The IAT is not yet universal for several reasons, both fiscal and technical. First, not enough funds are available for gathering and analyzing all the data. Second, the Air Force needs better, more automated, crash-survivable flight data recorders and reliable sensors for key parameters such as corrosive

environments. The LESS (loads and environmental severity survey) database gives more detailed and complete information on a few of the fielded aircraft (e.g., temperature and some corrosion indexes).

A recommendation in the 1997 NRC report addressed the issue of evaluating and implementing the following methods to provide earlier detection of corrosion: (1) investigation of environmental sensors to allow aircraft maintenance organizations to anticipate when conditions are likely to lead to corrosion; (2) evaluation of the applicability of the Navy's condition-based maintenance program to Air Force needs; and (3) development of techniques to locate, monitor, and characterize defects and chemical and physical heterogeneity within coatings. The goal of the program would be to develop corrosion-tracking methods that can scan an aircraft rapidly, detect thinning to within 5 percent, and provide a permanent record of corrosion found and corrective actions taken. Another recommendation supports the development of signal and image processing techniques based on technologies such as expert systems, neural networks, and database methods that could be used by aircraft maintenance facilities to interpret and track damage development and maintenance needs. If these recommendations are implemented, the health of fleets of aircraft could be ascertained annually and plans could be made to address aging aircraft problems.

Maintenance and Repair

The Air Force recognizes that bolted metal repairs are a mature technology. Thus, the primary emphasis in R&D has been on bonded repairs for both metal structures and composite structures. The most pressing problem for aging aircraft is bonded repair of metal structures. The current Air Force R&D program includes design and analysis techniques for composite patch repairs, repair procedures, design guidelines, and surface preparation for bonding. The 1997 NRC report recommended that the emphasis of the repair R&D programs be increased in the following areas (p. 69):

- technologies for the removal, surface preparation, and reapplication of corrosion-resistant finishes
- evaluation guidelines for the lives of bolted repairs, which are often called upon to remain effective for longer than a single depot-maintenance cycle
- guidelines for taking advantage of advances in materials and processing technologies in component replacement (including a review of certification requirements to see if they can be waived or simplified without compromising safety); an example would be the reduction of susceptibility to stress-corrosion cracking through the use of improved aluminum alloys, tempers, and processes to reduce residual stresses

- repair and analysis methods for maintaining structures susceptible to high-cycle fatigue
- maintenance and repair methods and guidelines for advanced composite structures

Several programs for repair technologies are either ongoing or planned. Those programs include the Composite Repair of Aircraft Structures (the development of bonded-repair design/analysis and validation tools); the Corrosion Repair of Metallic Structures (the development of bonded-repair design/installation guidelines); Sol-Gel Technologies for Metallic Surface Preparation; Durability Patch (damping/repair acoustic fatigue damage); RAPID (a software code developed by the FAA for metallic repair design and analysis); Development/Validation of Patch Inspection Methods; Commercial Aircraft Composite Repair (the development of repair techniques for conventional composite structures); Environmentally Friendly Adhesive Primer and Sealants; and High-Temperature Composite Structure Repair.

Many technology gaps must be filled in the overall arena of structural repair. Programs to address those gaps for composite doublers and conventional repairs could focus on repair design and analysis methods for sonic fatigue, standard repairs for corrosion damage, self-monitoring/smart patches, cold working as a repair option for short-edge margin holes, and repair of honeycomb and laminate structures.

A number of other issues must also be addressed, including issues associated with the conventional repair of composite structure, such as material degradation, design, and analysis; material supply management; improved processing for field-level repair; and damage tolerance versus NDI sensitivity. Other unresolved issues are associated with metallic structures, such as surface preparation; repair design and analysis; bondline durability prediction and accelerated testing; damage tolerance versus NDI sensitivity; documentation (procedures/guidelines) and certification of bonded repairs; repair material management; and smart patch technology. Future repair technologies should include standard repairs for corrosion damage; self-monitoring bonded repair patches; repair of aging composite structures; and incremental improvements in existing capabilities.

In summary, the Air Force's repair technologies program includes R&D on mechanically fastened and adhesive-bonded repair technology, with an emphasis on bonded repair. The program is addressing the 1997 NRC recommendations, and current programs could deliver basic mechanically fastened and bonded repair capabilities to ALC customers by FY03. Future needs include simple repairs for corrosion and self-monitoring, bonded-repair patches for safety of flight-critical structures. Many of these needs could be met through SBIR projects.

Operational Issues

Problems identified by the AATT that were not addressed above include lack of ownership cost models to facilitate repair, replacement, and retirement decisions and obsolete usage-monitoring methods. Ownership cost models that predict structural maintenance costs in out years would serve two purposes. First, the models would determine return on investment to support R&D. Second, they would provide data necessary for the modification, retirement, and replacement decisions. The development of these models will require detailed descriptions and a significant change in current business practices. Ownership cost models are also important to the commercial sector and thus present an opportunity for SBIR Phase III projects.

Usage monitoring is currently done by tape recording systems. The alternatives must provide an acceptable return on investment, significant improvements in data capture, and improved turnaround time in reporting. A new usage monitoring system should be integrated with corrosion monitoring and identify usage changes more rapidly than current systems. The new systems will also have to be acceptable to the ALCs, which will have to address problems identified by these systems. As funding allows, existing tape recorder systems could be replaced with microprocessor systems that can record information on aging aircraft.

Summary

The 1997 NRC report presented a list of recommendations for near-term and long-term research in the following categories: fatigue; corrosion prevention and control; SCC; NDE/NDI; and maintenance and repair (NRC, 1997). Since 1997, the AATT has put into effect a plan to address those recommendations. Nevertheless two important areas, corrosion and NDE/NDI, are not being adequately addressed.

INTERAGENCY ISSUES

Prompted by the results of the 1997 NRC report, the AFRL aging aircraft ITTP, in partnership with the ASC, undertook a joint planning activity with NASA and the FAA that confirmed the problems that had been identified and highlighted a number of areas of mutual interest (AFRL, 1997). Building on this beginning, the Joint Aeronautical Commanders Group (JACG) formed an action team on aging aircraft that included all of the services, many agencies, and industry. The principal goals of this team were to identify common areas of

interest and develop implementation plans to leverage resources. Workshops were held in 1998 and 2000, and the results were reported to JACG leadership.

Corrosion was identified as a critical problem by NASA, the Air Force, the Navy, the Coast Guard, and commercial aviation. It was not identified as critical by the FAA. The Air Force and the Navy identified numerous common corrosion-related issues. Not surprisingly, however, some of the technical issues important to the Air Force differed from those important to the Navy. The Air Force manages the majority of DOD's large transport aircraft, and although these aircraft are used by all of the services, their aging is an issue mainly for the Air Force. The Navy's fighter aircraft have more robust structural designs for carrier landings, must operate in a more corrosion-aggressive marine environment, and require significant maintenance aboard ship. Overviews presented at the 2000 Aging Aircraft Conference provided excellent summaries of areas of mutual interest and some new topics (UTC, 2000). For example, corrosion is becoming a major technical issue for space shuttles, which will remain in service for some time.

Many of the tools and products being developed overlap with other technical areas, especially NDE/NDI and structural integrity. A program identified by the JACG action team for near-term cooperation was the substitution of new materials for existing aluminum alloys and tempers. Programs addressing CPCs are of near-term interest to the Air Force and the Navy. One of the important issues that received the unanimous support of the services and industry was the need for fundamental research to provide a basic understanding of corrosion mechanisms and rates. Chromate-based coating replacement, smart coatings, and paint stripping were identified as important long-term issues by the Air Force and the Navy. In addition, the Air Force, the Navy, NASA, and industrial participants (Boeing, Lockheed Martin, and Northrop Grumman) all agreed that corrosion sensors, including fiber optics, for corrosion monitoring were of common interest. Appliqué technology is currently being investigated jointly by the Air Force and the Navy.

Common structural integrity issues were widespread fatigue damage, corrosion, unitized structures, and dynamics (e.g., sonic fatigue, buffet, and vibration). The focus areas for structural integrity technology included determination of the onset of WFD using deterministic and probabilistic methodologies; the development of structural analysis methodologies to assess the impact of corrosion and corrosion repair on life and residual strength; improvements in structural-analysis and life-prediction codes for unitized structures (e.g., castings). The interagency focus areas for repair technologies included repair of metallic structures (conventional mechanically fastened repairs and bonded composite doublers); repair of composite structures (conventional epoxy and high temperature); and life-enhancement methods, including advanced laser, shot peening, and cold working applications.

Several areas related to NDI were of common interest to agencies and industry. Crack detection was of interest to the Air Force, FAA, NASA, and industry. An information exchange has been initiated between an Air Force program that uses NDI to find cracks in fastener holes in thick structures (e.g., the B-1) and a NASA program on a low-frequency, self-nulling probe. The FAA's Airworthiness Assurance NDI Validation Center is coordinated with the Air Force study on POD protocol. A joint program between the FAA and the Air Force Commercial Aircraft Composite Repair Committee is addressing composite reference standards. The Air Force and NASA have a coordinated program on enhanced laser-generated ultrasound. In addition, the Air Force has an SBIR program on the development of a MEMS sensor for adhesion-bond degradation that will end in FY01. NASA will initiate a program on the same subject in FY01. In the area of NDI training, the Air Force, FAA, and NASA plan to initiate 1-year programs in FY01 on computer-based training radiography.

3

Air Force Small Business Innovation Research Program

OVERALL RESOURCES

Air Force resources allocated to the SBIR program are significant, approximately $200 million for FY00; this represents the second largest SBIR program in the federal government and about 40 percent of the resources in the total DOD SBIR program. The principal goals and objectives of the Air Force program are to support the warfighter through the insertion of SBIR-developed technological innovations into systems and subsystems and to increase both the level of participation among small businesses and the commercialization of SBIR technologies. Historically, the Air Force SBIR program has been managed by the AFRL, its S&T organization. This is still the basic approach, although recently the management stewardship was broadened to include the technology customers in order to focus on meeting critical customer requirements and improving the technology transition process.

These changes have also been driven by DOD guidance for SBIR program improvements issued by the undersecretary of defense for acquisition and technology in October 1998. Guidance on facilitating the transition of SBIR-developed technologies into DOD acquisition programs was summarized in a memorandum of August 1999 (DOD, 1999). Among the key provisions of this document is a requirement that the warfighting customer endorse at least 50 percent of the program by FY02. The long-standing baseline process and recent enhancements are described below.

Air Force SBIR resources have yielded important technological innovations and represent a significant addition to core Air Force S&T funding (PE 6.1–6.3), on the order of 16 percent in FY00 (Table 3-1). Because the S&T core budget has been decreasing (from $2.2 billion in FY87 to $1.2 billion in FY00), the relative impact of the SBIR program has been steadily increasing. Within the two program execution directorates of AFRL—Materials and Manufacturing and Air Vehicles—that are the major participants in the aging aircraft S&T program, the increase in funding via SBIR is similar, about 16 percent (Table 3-2).

TABLE 3-1 Proposals, Awards, and Funding for the Air Force SBIR Program (million $)

	FY96	FY97	FY98	FY99	FY00
SBIR program					
Proposals	3,793	4,003	3,285	2,794	2,444
Phase I awards	354	393	439	411	356
Phase II awards	194	211	243	152	
Budget	161.9	200.1	197.6	204.0	184.8
AFRL core budget (PE 6.1–6.3)	1,406.3	1,271.6	1,202.7	1,170.7	1,182.8

Table courtesy of Air Force Small Business Innovation Research Office.

TABLE 3-2 Proposals, Awards, and Funding for the SBIR Programs in the Air Vehicles and Materials and Manufacturing Directorates (million $)

	FY							
	Materials and Manufacturing				Air Vehicles			
	96	97	98	99	96	97	98	99
SBIR program								
Proposals	297	729	494	409	269	261	196	157
Phase I awards	36	59	55	43	19	21	26	23
Phase II awards	17	31	23	27	9	10	13	9
Budget	12.3	15.1	32.2	23.7	12.1	11.9	10.8	9.6
Directorate core budget (PE 6.1-6.3, 7.8)	105	112	108	106.8	90.8	85.3	78.4	81.9

Table courtesy of Air Force Aeronautical Systems Center.

The source of the Air Force SBIR funds is a corporate set-aside of 2.5 percent off the top of all extramural Air Force R&D accounts. For the AFRL, this represents a "tax" on the entire S&T account, excluding that fraction of the budget used to support personnel and in-house expenditures (intramural accounts). The set-aside is also applied to the acquisition R&D accounts of the Air Force product centers and the program executive officials (PEOs). For aging aircraft, this is the Aeronautical Systems Center (ASC) and the PEO programs (such as the F-22 and the Joint Strike Fighter). Test centers and ALCs are also "taxed," but they have a much smaller R&D base.

BASELINE PROCESS

SBIR Topics, Topic Allocation, and Phase I Contracts

The SBIR process begins with the creation of descriptions of technical topics, new technologies that would meet the requirements of key units across the entire Air Force. The descriptions, typically two pages long, reflect current research themes and requirements. After approval by DOD, these technical topics are distributed to the SBIR business community in an annual SBIR proposal solicitation published in *Commerce Business Daily* and on the DOD SBIR Web site, <www.acq.osd.mil/sadbu/sbir>. The full process description, the topic listing, and key contacts for administrative and technical assistance are also posted. An open preproposal period follows, during which prospective participants can engage in technical discussions with the topic sponsor. The small business community then submits Phase I proposals. The selection of Phase I proposals is competitive, based on technical merit. A current ground rule used by the Air Force is to award at least one Phase I program for each SBIR topic. On average, approximately 10 percent of proposals are awarded Phase I programs.

In the baseline process, the topic allocation step is important for at least two reasons. First, for small businesses, Phase I competition is the entry point into the entire process, including positioning to compete for the much larger Phase II and Phase III funding and eventual technology transition (Figure 3-1). Second, because the number of topics is limited, Air Force participants must compete to have their topics selected for the program solicitation. If a topic is included, it assures Air Force managers that their core program will be augmented by SBIR projects and that innovations flowing from the small business community will be applicable to their needs.

Topic selection, SBIR contractor awards, and contracts administration are the responsibility of the AFRL directorates. The SBIR team at AFRL headquarters provides policy guidance, fiscal oversight, and resource allocation through established processes developed and approved by the Air Force and the AFRL.

Phase II Contracts and Phase III Implementation

If a relatively short, modestly funded Phase I program is successful, the SBIR company is invited to submit a Phase II proposal. The program awards for Phase

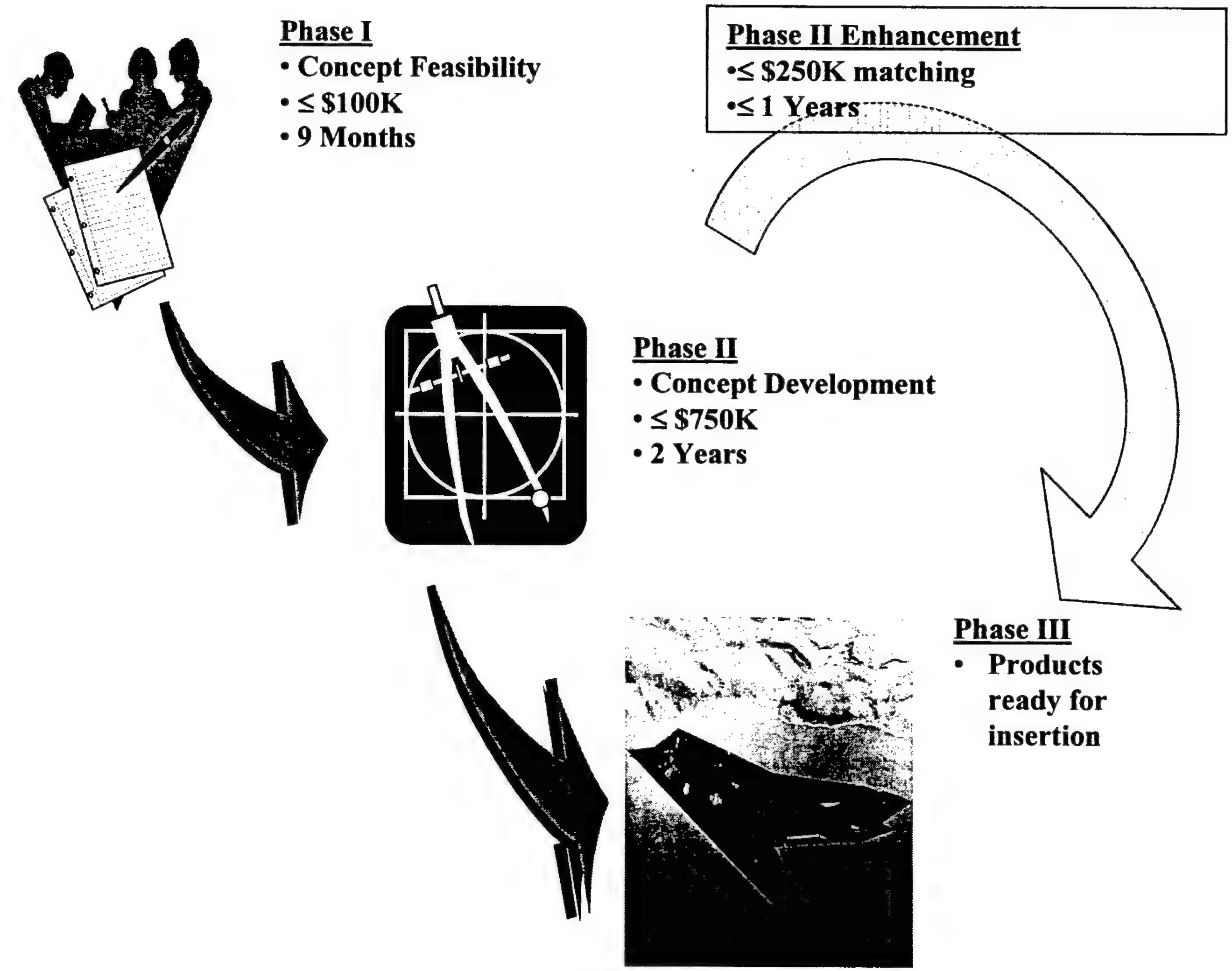


FIGURE 3-1 Three phases of the SBIR program. Figure courtesy of Air Force Small Business Innovation Research Office.

II are much more substantial than for Phase I. A general AFRL rule of thumb is that the number of Phase II awards should be approximately 50 percent of the number of Phase I contracts. Thus, overall, approximately 5 percent of the initial Phase I proposals lead to Phase II program awards.

To facilitate technology transition and commercialization, SBIR program provisions allow up to 33 percent of Phase I and 50 percent of Phase II programming to be shared with a partner company that is not a small business. Thus, if the eventual market for the technology is limited to the military sector, it may be attractive for the small business to team up with an aerospace industry prime contractor to facilitate technology transition. Striking the right partnership terms, particularly when it comes to protecting the intellectual property rights of small businesses, is a significant challenge.

Under the SBIR funding umbrella, there are opportunities for a Phase I fast track and a Phase II enhancement. For the Phase I fast track, if the SBIR investor offers outside capital, the Air Force will consider providing up to four times that amount in matching funds. The fast track offers expedited processing and significantly better chances of Air Force support. The Phase II enhancement process requires non-SBIR military matching funds up to $250,000 to help resolve technical barriers discovered during normal Phase II R&D. As the research proceeds, new challenges and opportunities may emerge, and the Air Force SBIR program manager may launch a new round of Phase I or II programming in the same general area to deal with these issues.

The follow-on Phase III funding from the Air Force, for example from the core AFRL S&T budget, is not generally the final step in successful technology implementation. As a practical matter, although this next step is called commercialization, in some cases the funding is used for exploratory development (PE 6.2) or advanced development (PE 6.3) that may still fall well short of the adoption of the technology by the ultimate customer. Many technologies require other phases of acquisition programming before they are considered ready for insertion into a system or subsystem. This may include demonstration and validation (PE 6.4) or engineering and manufacturing development (PE 6.5). Final customer application, for example, for an aging aircraft system like the C-141, will require acquisition funding from this SPO or sustainment funding from an ALC. Special challenges to technology implementation in the sustainment arena will be discussed in Chapter 5.

Innovation generally implies both risk and significant payoffs. Experience has shown that in fields such as new materials technology the total time from identification of the new technology to ultimate practical application usually ranges from 10 years to more than 20 years, even if appropriate and timely funding is available at every step (NRC, 1999b).

In the baseline process, the steps to application after Phase II are (1) incorporation of the technology into the AFRL core strategy and into its core

resource road maps and (2) the acceptance and funding of final transition and implementation by an ALC, a test center, or the acquisition programs of a particular DAC. Completing all of these steps is a formidable challenge for small businesses, which must rely heavily on the Air Force team's integrated transition strategy and its dedication to assisting with implementation issues.

PROCESS METRICS AND TIME PHASING

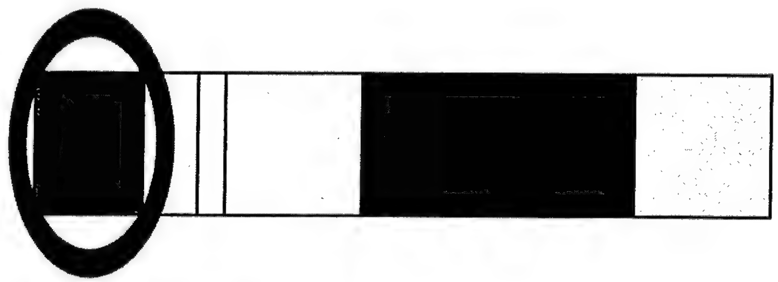
As shown in Figure 3-2, the steps in the SBIR process, from topic definition by the Air Force to completion of a Phase II enhancement program by the small business, takes about 5 or 6 years. Significant additional funding and time may be required in Phase III before the technology can be implemented by the ultimate customer. In a given program area at any point in time, many SBIR programs are under way, each in a different phase (Figure 3-3).

Under the original baseline SBIR program, the number of topics and the SBIR funding allocated to each AFRL directorate were proportional to the directorate's core S&T budget (Table 3-3). The number of Phase I awards triggers Phase II funding requirements. Thus, the award ground rules mentioned above, the current statistics on active programs, and the level of directorate core S&T budgets provide the framework for the annual SBIR funding distribution decisions by the AFRL headquarters team.

Commercialization

Phase III is focused on commercialization, although this term means more than simply the commercial-sector application of Phase II program results. Commercialization is defined as the use of any non-SBIR funding that moves the technology a step closer to application. Thus, Air Force core S&T funding applied to further an SBIR-developed technology is considered commercialization.

If the Air Force or the military is the only customer for an SBIR technology, the market will obviously be severely limited, which raises business viability issues for small businesses. A dual-use market of military and commercial nonmilitary customers is much more desirable for both the Air Force and the small business. The Air Force can leverage the commercial market with the military market and vice versa. In addition, Air Force managers will be motivated to assist the small business in developing the nonmilitary applications of the technology. In fact, potential commercial success is an important criterion in the competitive SBIR contract award process.



WRITE TOPICS

- Aug - 30 Nov - PEO/DAC develop first draft topics
- 14 Feb - AFRL/TDs develop drafts in concert with DOD review criteria
  - -- Informal iteration between topic sponsors and technical POCs
- 30 Mar - Topics completed (meet 6 DOD criteria)

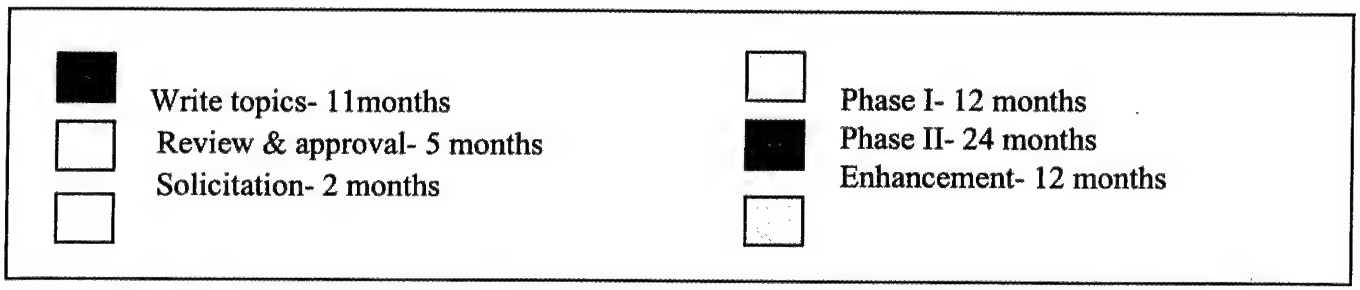


FIGURE 3-2 SBIR process cycle: phases of a single cycle. Figure courtesy of Air Force Small Business Innovation Research Office.

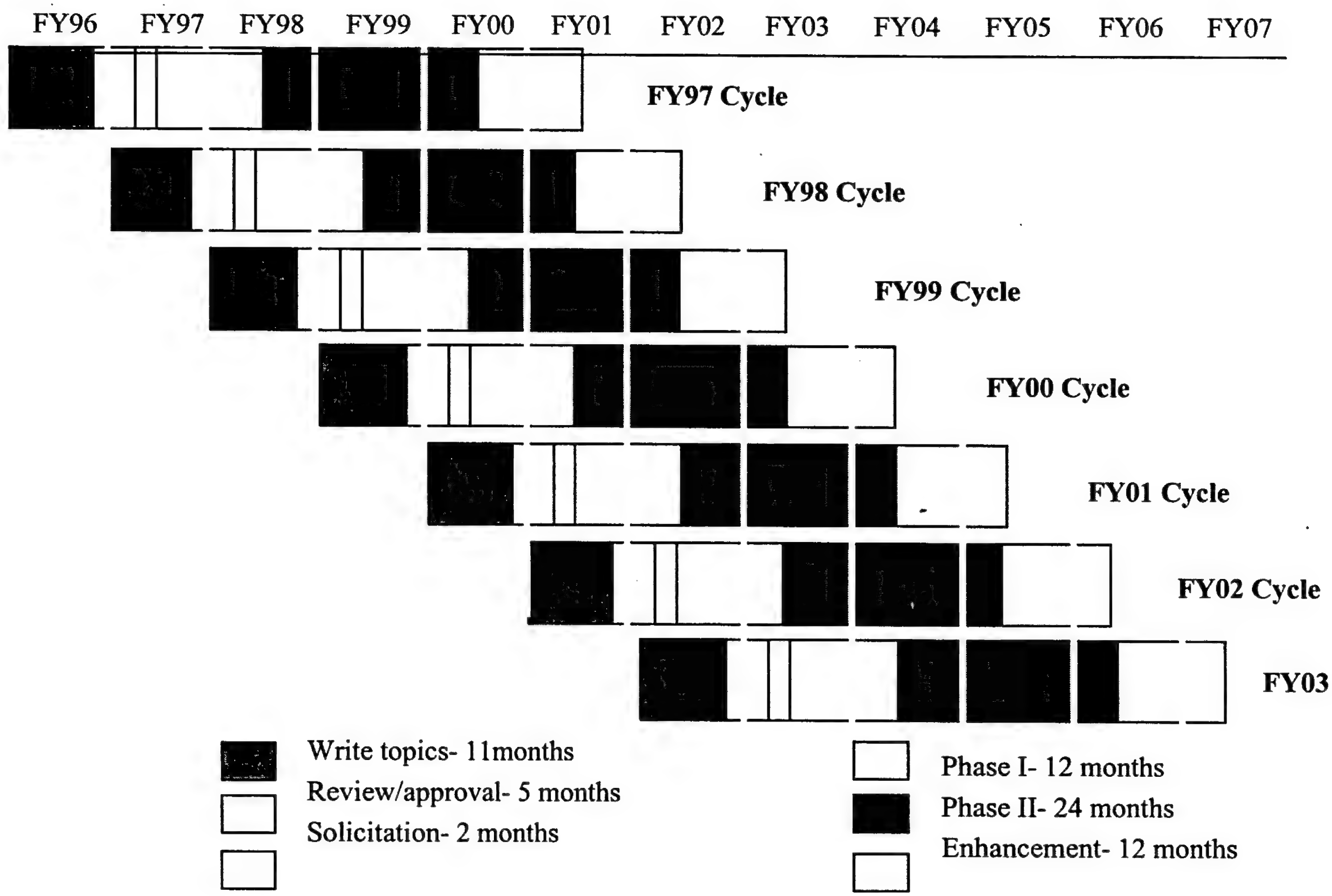


FIGURE 3-3 SBIR process cycle: multiple projects underway, by fiscal year. Figure courtesy of Air Force Small Business Innovation Research Office.

Table 3-3 SBIR Topic Allocation: Baseline Process (FY00)

Directorate	Number of Topics Allocated
Munitions	17
Air Vehicles	18
Directed Energy	21
Human Effectiveness	24
Information	28
Materials and Manufacturing	28
Sensors	28
Propulsion	36
Space Vehicles	40
TOTAL	240

Table courtesy of Air Force Small Business Innovation Research Office.

Even if they have not previously participated in an SBIR program, all companies must submit a Company Commercialization Report, which shows the quantitative results of the firm's prior SBIR projects. Since 1999, DOD has developed a commercialization achievement index (CAI) for firms with five or more Phase II awards prior to 1998; firms with fewer than five awards are given a CAI of N/A. The CAI, along with Phase II sales and investment information and explanatory material, is considered when evaluating proposals for their potential commercial applications.

For example, consider a firm that received 10 Phase II SBIR awards through 1997 and has an index of 95. If the firm's 10 awards were compared with a group of 10 DOD SBIR/STTR awards selected at random from the same time period, there would be a 95 percent chance that the commercialization resulting from the firm's awards would exceed the commercialization resulting from the randomly selected group. As a basis for this calculation, DOD maintains a database of Phase II projects awarded between 1984 and 1997. The data include sales revenue from new products and non-R&D services resulting from Phase II technologies; additional investments in technologies from sources other than the federal SBIR/STTR programs; and the percentage of additional investments that qualifies as hard investment.

PAST SBIR TOPICS ON AGING AIRCRAFT

A survey of the SBIR awards listed on the Web sites of the Air Force and Navy revealed that very few topics fell under the category "aging aircraft." However, many of the awards could be relevant to aging aircraft. In fact, the only way to determine the suitability of a topic for the aging aircraft category is by reading the abstract. Of the 1,800 abstracts of awards from 1993 to 1998 read by the committee, 108 were selected for the sampling study. Twenty-seven abstracts related to nondestructive testing methods, 18 related to joining issues for metals and composites, 24 called out methods of detecting corrosion and corrosion fatigue, 18 related to the development of materials for components that could be used in retrofitting aircraft, and 21 related to the development of processes and methods of coating/cleaning surfaces. Many abstracts related to new materials and processes to replace existing materials on various aircraft systems. Because many awards are made in generic topics such as coatings or nondestructive testing, they cannot be classified as being part of the aging aircraft program, although many are clearly suitable for aging aircraft systems.

Most of the FAA and NASA awards surveyed were related to the development of databases and the development of materials and models to understand fatigue behavior. A few topics were related to methods to corrosion prevention; many topics were related to nondestructive testing and techniques to develop new materials. A few FAA programs cited aging aircraft as the end application; no specified NASA awards were targeted at aging aircraft.

The committee attempted to determine levels of commercialization based on information on the Web sites of many of the companies that had received awards. Almost no useful information was derived from this effort, however. DOD and the Air Force collect data to arrive at the CAI for each company, but these data are not available for public use. Thus, the committee was unable to obtain actual sales numbers for specific companies and awards.

Findings and Recommendations

Finding. Solicitation for a Phase I topic, selection, award, submission of a Phase II proposal, award, and completion usually take 5 to 7 years. This is too long for the Air Force to wait for solutions to the most pressing problems of aging aircraft. Interaction and coordination among the government agencies on the topics selected for Phase II awards are minimal.

Recommendation. An interagency working group should be established by federal agencies that participate in the SBIR program to review all Phase II awards that are technically meritorious but have been rejected for lack of funding or other

reasons. To shorten the long gestation time and bring products to end users more quickly, a small portion of the SBIR budgets of defense agencies could be used to leverage funding with the civilian agency SBIR programs, especially in the areas of sensors, corrosion detection, and NDE. A secondary objective of the interagency group should be to partition the programs by subject for 2 or 3 years. For example, the Navy could fund projects on corrosion, the Air Force could fund projects on NDE, and the Army could fund projects on sensors.

4

Priority Technical Areas

The committee identified two interrelated technical categories that merit more attention by the SBIR program. These areas can be classified broadly as corrosion (other than general corrosion, but including galvanic corrosion and corrosion fatigue) and nondestructive evaluation and investigation (NDE/NDI). Specific topics are described below.

Corrosion modeling. Corrosion modeling, especially for hidden forms of corrosion (galvanic corrosion, crevice corrosion, pitting, intergranular corrosion, stress corrosion cracking, and corrosion fatigue) is a priority R&D area. In general, corrosion is currently detected from empirical data, and the onset of corrosion or the propagation of corrosion in the presence of stress or fatigue cannot be predicted. Predicting the onset of corrosion for a particular component or a particular aircraft, with or without other damage mechanisms, is very difficult. However, susceptible structures could be identified and corrosion rates predicted.

Models of the effect of multiple coating layers on corrosion behavior would be useful for predicting the remaining life of systems. Such models could be developed through the SBIR program to provide concepts, a general framework, and assumptions for different materials. Models would be key elements in determining structural life (see Figure 2-4). If significant innovations are achieved in modeling corrosion growth rates, strong commitments for Phase III funding will be necessary. Because the modeling of corrosion phenomena is of considerable interest to many agencies, leveraging of funds is a good possibility.

Nondestructive evaluation and investigation. NDE/NDI modeling to detect subsurface cracks and hidden corrosion in fastener holes and beneath coatings is one of the most significant areas for R&D. The development of several NDI systems is being done by small businesses; the Air Force will need new techniques or hybrid techniques to improve both the identification and quantification of the defect. Quantified values, which could then be fed back into models developed to predict remaining life, would play a vital role in determining maintenance or inspection intervals, both of which affect operation and support

costs. Small business programs are ideally suited for the development of these NDE/NDI methods, which address specific, focused areas that could result in Phase III successes.

Senior technologies. Significant developments in sensor technologies are being made rapidly. Sensors and sensor analysis—including embedded and external sensors for measuring pressure, temperature, humidity, gases, color, corrosion, cracking, thickness, local strain, and chemical composition—are important for the future of aging aircraft. Sensors come in many forms, shapes, sizes, and qualities, and each type can provide useful information for modeling. Sensors can also serve as early warning systems of impending failures or the need for accelerated maintenance. Sensors that can measure thickness at regular intervals could become an integral part of future aircraft systems. Many advances are being made in optical, ultrasonic, and chemical sensors, as well as MEMS, miniature systems, wireless technologies, and diagnostic and prognostic analysis tools.

Coatings. Coatings are used on aircraft for many reasons, ranging from camouflaging to corrosion protection. Coatings protect surfaces from the environment and contribute synergistically to overall service life, but they may weather with time and use. The removal of coatings without leaving traces of ingredients that may adversely affect the surface or the environment is an important area that merits attention by the SBIR program. Health issues associated with the removal of coatings also merit attention.

The AFRL medium-term coatings development program has been very successful. Attention has now shifted to the difficult issues of long-term coatings development. The SBIR community could make contributions in this area as significant as those it made for earlier coatings. Materials development for the long-term program includes new polymer technology, chromate-free corrosion inhibitors as the core of the permanent primer, and innovative tailoring of the total coating system for durability and cost-effectiveness.

Surface treatments. Surface treatments (mechanical and thermal) to relieve stresses or to create residual stresses would increase fatigue life. Issues related to the role of these stresses and their interactions with the environment can influence the safety factors incorporated in designs for aircraft structures. Prolonging service life through surface treatments is an area suitable for small business activity.

Remanufacturing and repair. Aircraft structures are damaged by bird hits and impact damage from flying or runway debris. In light of the high cost of structural materials and the need to ensure that readiness has not been compromised, remanufacturing techniques that can be applied at the ALC level would be

extremely useful. These techniques would have to be simple, easy to use, environmentally compliant, and relatively inexpensive. Because they would be used by routine service personnel with minimal education, they would have to be easy to learn, easily transferable, and consistent in quality. Remanufacturing and repair technologies are promising candidates for many SBIR programs, especially for the aging aircraft program.

Composites. The development of high-strength, stiff, easy-to-manufacture composites that can be bonded or attached to similar or dissimilar structures would be of immense value to the Air Force at the ALC level. An understanding of how composites could be used in various environmental conditions, the interfacial strength, and the degradation rates of interfaces would also be of great benefit. The focus of the Air Force's repair technology program is on highly reliabile and long-lasting bonded repair of metallic structures using composite materials. Methods of qualifying bonds, new materials for bonding, and methods of establishing acceptable levels of strength created during bonding could be good candidates for SBIR projects.

Miniature sampling methods. Small samples that provide representative bulk data is another area of significant interest, especially for composites or precipitation-hardened alloys. In such materials, the interface/environment effects may increase stress levels, decreasing the fatigue or corrosion-fatigue life. Reliable methods of sampling and analyzing data could help to establish and improve safety factors in design.

Cost ownership models. The cost of maintaining an aircraft throughout its lifetime and the ability to make intelligent decisions based on the relationship between useful service life, readiness, and cost of upkeep will require the development of cost ownership models. Most aging aircraft in the fleet have already outlived their planned service life, and the cost of upkeep for the fleet for the next 20 to 25 years is not known; many issues that will affect operation and maintenance costs or even safety have not been identified. The Air Force does not have cost ownership and usage models to help plan the retirement of aircraft, develop maintenance interval guidelines, and make early budget allocations in an austere environment. A number of the available cost models currently being successfully adapted by a number of Air Force groups for their analyses of cost of ownership and economic service life originated in SBIR programs, and the SBIR community could play an important role in developing or adapting these models for aging aircraft.

Recommendation. The committee recommends that more emphasis should be placed on using the Small Business Innovation Research (SBIR) program in the near term to solve problems related to localized corrosion (including galvanic corrosion and corrosion fatigue) and nondestructive evaluation and inspection (NDE/NDI). Solutions to the problems of (1) modeling and understanding galvanic corrosion, stress-corrosion cracking, corrosion fatigue, and all the other insidious forms of corrosion and (2) developing tools for NDE/NDI and software to analyze data in these areas should be solicited from the small business community. Because many of the innovations will be specific to the Air Force, the end user (in the Air Force) should be involved in the Phase I and Phase II award process. In addition, if the innovation is Air Force-specific, non-SBIR funding for Phase III may be an Air Force responsibility.

5

SBIR Process Improvements

The focus of this report is on technical recommendations for using SBIR to support aging aircraft. In this context, the committee also reviewed Air Force SBIR processes in some detail and determined that changes in certain SBIR administrative processes would help the Air Force to address aging aircraft technologies, as well as technology in other areas. The committee did not consider all potential SBIR process improvement options and alternatives, but it offers some recommendations for careful consideration by the Air Force. Because only SBIR projects related to aging aircraft were considered, the Air Force will have to determine if these recommendations also apply to other aspects of its SBIR program. The recommended process improvements are based on the committee's evaluations of the Air Force's SBIR program in Chapter 3 and presentations by the Air Force (see Appendix B).

NEW SBIR PROCESS

The process improvements summarized in the memorandum of August 1999 (DOD, 1999) are intended to facilitate the transition of SBIR-developed technologies to the warfighter. The memorandum includes the following directives:

1. Major acquisition programs must designate an SBIR community liaison.
2. Links between SBIR solicitation topics and acquisition program needs should be established.
3. A system should be developed enabling SBIR contractors to contact potential customers/investors in DOD prime contractors and elsewhere.
4. Acquisition programs and the private sector should be able to leverage their investments in SBIR technologies.
5. Senior acquisition executives should issue guidance to acquisition programs for including SBIR as part of their ongoing program planning.
6. Metrics of how well acquisition programs have integrated SBIR technologies into their program should be implemented.

7. Acquisition programs and SBIR communities should be educated on the process for, and the advantage of, integrating SBIR technologies into acquisition programs.

Air Force implementation of these DOD directives is a phased process intended to increase customer involvement to ensure that (1) the requirements of the customer are being met by the SBIR program and (2) customers actively participate in and support the technology transition and implementation strategy to increase the likelihood of success. Including sustainment customers (ALCs) directly in this process and in the acquisition programs is a significant change for the aging aircraft community.

The basic strategy for improving Air Force SBIR processes is to change the SBIR topic allocations, the most powerful tool in the whole process. The topic allocation themes include:

- *Taxation with representation.* Executive officials of Air Force programs are allocated topics in proportion to their SBIR program funding contributions, which are based on the proportion of R&D in their program portfolios.
- *Balanced representation for all customers.* Topics are allocated to product centers, logistic centers, and test centers, all of which have important requirements for technology innovation and are the managers of acquisition and sustainment programs.
- *Balanced representation for technological experts.* The remaining topics are divided equally among AFRL directorates.

The results for the new topic reallocations are summarized in Table 5-1. Topic allocation under the baseline process (see Table 3-3) was made only to AFRL directorates in proportion to their R&D accounts at that time. The total number of SBIR topics for both the baseline (240) and the new process (234) is based on total funding of the Air Force extramural R&D accounts. The small difference between the totals reflects a small reduction in the total Air Force extramural R&D budget. The AFRL also manages the SBIR programs of other DOD agencies, such as the Ballistic Missile Defense Organization (not included in these totals). In practice, Air Force SPO allocations are not made to individual systems but to PEOs. For example, the fighter/bomber PEO portfolio managed in the Pentagon includes the F-16, F-15, F-22, F-117, B-1, and B-2.

Table 5-1 shows that the major difference under the new process is that 170 of the 234 topics (about 75 percent) are now assigned outside the S&T Directorate to the product centers, test centers, ALCs, and SPOs (through PEO portfolios). The proportions of R&D resources range from almost zero to more than 40 percent.

Table 5-1 SBIR Topic Allocation: New Process (FY02)

Organization	Allocation
Program Executive Officials	
Joint Logistics	0
Weapons	21
Joint Strike Fighter	10
Fighter Bomber	22
Airlift and Trainer	8
Space	47
Command and Control	10
Total	118
Product Centers and Test Centers	
Product Centers	
Air Armament Center	6
Aeronautical Systems Center	6
Electronic Systems Center	6
Space and Missiles Center	6
Test Centers	
Arnold Engineering Development Center	6
Air Force Flight Test Center	6
Air Armament Test Center	6
Total	42
Air logistics centers	
Oklahoma City Air Logistics Center	6
Ogden Air Logistics Center	6
Warner Robbins Air Logistics Center	6
Total	18
Air Force Research Laboratory Directorates	
Munitions	6
Air Vehicles	6
Directed Energy	6
Human Effectiveness	6
Information	6
Materials and Manufacturing	6
Sensors	6
Propulsion	6
Space Vehicles	6
Corporate Strategy	6
Total	60
GRAND TOTAL	248

Table courtesy of Air Force Small Business Innovation Research Office.

The process steps used to select the technical opportunity areas, which become the subjects of individual SBIR topics, encourage a continuing dialogue among technology program managers, acquisition program managers, and warfighters. These steps include the posting of a large number of potential topics by each AFRL directorate on the AFRL SBIR Shopping List Web site, <http://aftech.afrl.mil/sbir/index.htm>, reviews and evaluations of these topics by the acquisition, sustainment, and warfighter stakeholders, consolidation of laboratory, product center, and PEO topics by the AFRL, and implementation by AFRL of the entire SBIR process for all stakeholders. Customer stakeholders can of course generate their own SBIR topics, but because they may have limited expertise and limited staffs, the AFRL-generated listings may be more useful. Customers can select a proposed AFRL topic directly or tailor it to meet their needs. This is also beneficial to AFRL because each directorate manages not only its own topics (six per directorate) but also the topics of customers who have tailored AFRL-recommended topics. In one respect, AFRL, in effect, still manages the majority of SBIR programs. The positive new element is that many of the programs now have the direct endorsement and participation of acquisition managers and warfighters.

At present, the ALCs manage their own SBIR programs and do not rely on AFRL support. They participate, however, in the broader process of defining topic subjects and shaping some of the subjects selected by others. AFRL senior management in each directorate makes the final decisions on the subject matter of the six topics directly under its control.

As might be expected, the current listing of SBIR topics from the ALCs is dominated by aging aircraft issues. These centers have limited direct access to R&D funding, so SBIR program participation is something of a windfall for them, and they have expressed considerable interest in expanding their participation. Table 5-2 is a summary of the effects of new processes on SBIR programming in the structures-related aging aircraft arena for FY00 in the Materials and Manufacturing Directorate and the Air Vehicles Directorate. Because the process recycles annually, the total for aging aircraft or any other topic can change each year. The more important point is that a number of these topics are now customer-endorsed or -generated.

Two things are made clear by Table 5-2: (1) the product centers are using their allocated topics for the potential benefit of aging aircraft and (2) the Air Vehicles Directorate and the Materials and Manufacturing Directorate are not concentrating on the problems of aging aircraft. Thus, some means must be found for providing the AATT with some SBIR topics pertaining to its responsibilities even though AATT does not contribute to the funds set-aside.

Table 5-2 SBIR Topic Allocations for Aging Aircraft

	Air Vehicles Directorate	Materials and Manufacturing Directorate
Baseline process (FY99)		
Total topics	18	28
Aging aircraft topics	3	2
New process (FY00 and beyond)		
Directorate-generated SBIR topics	6	6
Directorate-generated aging aircraft topics	1	0
Product center/PEO-generated aging aircraft topics (B-1, B-2, F-16, F-117, C-130, ASC)	2	4
Total aging aircraft topics (new process)	3	4

Table courtesy of Air Force Aeronautical Systems Center.

As the new Air Force process matures, further improvements will be necessary. First, the topics must be coordinated among all participants. As Table 5-3 shows, stakeholders sometimes independently propose closely related topics; the development of a collective strategy for these would be of great benefit for both the Air Force and the SBIR community. A second important process improvement will be top-down topic selection. If the number of technical areas (of which aging aircraft could be one) is limited, the SBIR funds allocated to aging aircraft might increase. The focus topics would be managed through the AFRL ITTP, which deals with laboratory technologies targeted for transition. A new companion process aimed even more broadly at developing more effective technology transition is being introduced by the AFRL/ALC/MAJCOM partnership: the Applied Technology Council. SBIR focus topics, given significant funds, could become key elements of both the ITTP and the Applied Technology Council processes for ensuring the complete development and successful transition of new technologies.

Table 5-3 Topics Related to Corrosion Fatigue of the C-141 and KC-135 Proposed by Different Stakeholders

Stakeholder	Topic
Warner Robbins Air Logistic Center	Sustainment programming: C-141 SPO
Oklahoma City Air Logistic Center	Sustainment programming: KC-135 SPO
Aeronautical Systems Center: Mobility Mission Area Group	Acquisition programming: C-141 and KC-135
Airlift and Trainer PEO	Development, modernization, and sustainment programming for the Air Force mobility forces
AFRL Air Vehicles Directorate	Structural integrity analysis tool set development: corrosion fatigue analyses
AFRL Materials and Manufacturing Directorate	Materials technology for prevention and management of corrosion degradation

Table courtesy of Air Force Aeronautical Systems Center.

TECHNOLOGICAL INNOVATIONS FOR SUSTAINMENT

One of the difficulties in the development of technological innovations for existing flight vehicles is that the budgeting process of the Air Force tracks monies for different purposes in different accounts (i.e., monies from different accounts are considered to have different "colors"). The R&D programming managed by AFRL (in RDT&E [test and evaluation] Appropriation Account 3600: Program Elements 6.1, 6.2, and 6.3) and the systems acquisition programming managed by the product centers and PEO's (Account 3600: PE 6.4-6.7, including the aging aircraft acquisition program [PE 6.5]) are tracked in one account. These funds are separate from funds for sustainment (Appropriation Account 3400: Operation and Maintenance), managed largely by the ALCs.

Most new technologies are for new systems that will be fielded sometime in the future, and transferring them requires AFRL, the product centers, and PEOs employing sequential 3600 Program Element funding to work together. The development, transitioning, and implementation of technologies for existing systems requires partnering between the AFRL, product centers, PEOs, the ALC, and, perhaps, the flight-line customers who perform day-to-day maintenance. This process requires both 3600 and 3400 program funding. This extended technology-

transition track adds to the responsibilities on the overall Air Force team, which must provide as seamless a process as possible to ensure the successful implementation of new sustainment technologies. The new ASC Aging Aircraft Program Office, funded with PE 6.5 acquisition resources, was created to provide bridge funds for this process.

Because of the way the sustainment arena functions, the identification of high-payoff technologies may be difficult; the implementation of technology solutions, even when shown to have high payoff, may also be difficult. As Admiral Massenburg pointed out at the 2000 Aging Aircraft Conference (Massenburg, 2000), the multiple reporting systems, documenting problems, and subsequent maintenance may be a Tower of Babel of different formats and standards. Much of the key information, particularly trend data, can be lost because maintenance data are sometimes retained for only a few months. In addition, maintenance reporting may not even contain sufficient information to identify the fundamental engineering causes of problems.

A number of aging system program offices in the Navy and the Air Force are taking definitive action to facilitate the consistent identification of cost-effective sustainment actions. An example of the new process, the C-5 aircraft enterprise model, was presented at the conference (Compton, 2000). With the enterprise approach, what is going on today is evaluated to establish baselines for all elements of aircraft availability and ownership costs. Then an assessment is made of essential near-term and long-term improvements, and the criteria necessary to achieve the best return on investment for both aircraft modernization and sustainment are identified.

When potentially cost-effective solutions have been developed, completion of all steps for successful implementation at an ALC or on the flight line may be a real challenge. A number of steps may be required at the ALC for full implementation (e.g., preparation of technical orders or detailed maintenance manuals, completion of facility hardware and software upgrades, purchase of new supplies and equipment, and purchase of new replacement parts). Each step may require action by different parties subject to different processes to secure the required funds. In addition, AFRL and acquisition team members must absolutely ensure that all development and system engineering work has been completed before proposing that ALC adopt new technologies. The ALCs have very limited "sustaining engineering" resources, and these must be used to fulfill their principal mission of aircraft maintenance.

Although these issues may not directly concern the SBIR community, an appreciation of the overall process is important for a successful technology transfer. Fortunately, the military services are taking concerted steps to improve the processes for introducing new technologies into the sustainment arena. These initiatives include the new Navy Aging Aircraft Integrated Product Team, introduced at the 2000 Aging Aircraft Conference; annual Air Force durability

surveys of the entire aging aircraft fleet; the Air Force Aging Aircraft Working Group; and actions by individual SPOs, such as that for the C-5. However, no fully integrated Air Force team applying a coordinated and focused programming approach has been established.

RECOMMENDED PROCESS IMPROVEMENTS

The recommended process improvements are based on the committee's evaluations of the Air Force's SBIR program in Chapter 3 and presentations by the Air Force (see Appendix C). Because only SBIR projects related to aging aircraft were considered, the Air Force will have to determine if these recommendations also apply to other aspects of its SBIR program.

Selection of SBIR Topics

Some representatives of Air Force units that made presentations to the committee felt that because they did not have sufficient control over the SBIR process, they did not plan on using SBIR funds for flight-critical programs. This is easy to understand, because the operating units submit topics for consideration but do not make the final decision on which topics will go forward. Topics are currently selected and approved at the higher echelons of the DOD and then returned to the operational levels for implementation. Further, SBIR resource commitments for Phase II are made at the higher echelons of the Air Force.

If a significant level of SBIR funding is routinely provided to ITT areas by rotation, then Air Force technical managers, who develop the S&T core-funding road maps, can incorporate an SBIR funding wedge as an integral part of the overall strategy, which would include practical plans for commercialization.

Finding. The current process of selecting SBIR topics is time consuming and may actually stifle the use of SBIR funds for time-critical innovations.

Recommendation. Final decisions on SBIR topics should be made at the operational level (the air logistics centers [ALCs], system program offices [SPOs], product centers, test centers, or laboratory directorates) so that the process of selecting SBIR topics can be shortened considerably.

Recommendation. A smaller number of topics with resource commitments for the full cycle would allow the Air Force to focus on major areas (each of which would encompass multiple topics) based on an Air Force-wide development strategy. Focus areas should be rotated systematically in response to evolving Air Force requirements and to ensure that areas left out in earlier cycles receive attention. Aging aircraft should be one of the first focus areas to be implemented. The committee suggested that about 40 percent of the SBIR funds could be set aside for the focus areas.

Recommendation. The process should be implemented through the six Air Force Research Laboratory integrated technology thrust (ITT) structures and the program arenas in them (the 29 ITTPs), of which aging aircraft is one. For example, four ITTP areas could be given all of the money in one year, along with funding commitments for out years. This would enhance the value of a given ITT area based on Air Force need in relationship to warfighter and sustainer requirements. The ITTs are the recommended vehicle for implementing focus topics because they are responsible for ensuring technology transition to meet high-priority warfighter and sustainer needs.

Recommendation. Customer stakeholders, now full partners in the SBIR process, should become full partners in developing the major focus areas. In this way, they would be contributing topics and contributing implementation resources (and, of course, they are the ultimate beneficiaries).

In the current SBIR program implemented by AFRL, there is no programmatic flexibility to allow for sudden, new, or unforeseen needs. In addition, there is no provision to support new directions or programs that might require innovation support or to support an existing program for which a funding concentration is needed over the short term.

Recommendation. A pool of SBIR funds should be made available on a case-by-case basis to agencies, programs, depots, or laboratories that can document a need for short-term SBIR support. If each agency, command, program, depot, or laboratory that now has six topics available to it were given five topics instead, a pool of topics (and of SBIR funds) would become available for an open competition or assignment on an annual basis according to demonstrated, documented needs.

Transition from Phase II to Phase III

In some cases, SBIR funding is simply the front-end cost of development programs to test the feasibility of full development programs. In these cases, the "sponsoring" manufacturer, depot, laboratory, or agency is expected to furnish at least some of the support necessary to bring a program to fruition. In fact, several programs may be able to contribute funds for the completion of an innovation in which they are all interested. Another advantage to this approach concerns the flow of information during a development program. If funding for Phase III is provided by a government agency, it will facilitate use of the innovation at the much-needed ALC depot level.

Finding. SBIR funds now cover Phases I and II. Private funding is usually used to fund Phase III and beyond, although this is not mandatory.

Recommendation. If the Air Force is the only customer for an innovation developed with SBIR funding, the Air Force Research Laboratory, the system program office, and/or the program manager should take ownership by funding these innovations beyond Phase II with non-SBIR money. Once an SBIR-funded project has developed a desired necessary innovation, the user agencies should be prepared to transfer successful developments to normal internal funding sources to complete development.

Recommendation. SBIR proposals should have complete manufacturer, system program office, agency, or depot backing when Phase I proposals are selected for award. That backing should be a simple but forceful statement to the effect that "we need it, so if it works and is affordable (cost-effective), we will use it."

White Paper Process

Air Force SBIR program managers do not appear to consider the significant costs involved in preparing an SBIR Phase I proposal. Small businesses estimate the current cost at $3,000 to $10,000, a significant investment for a very small business. Many more small businesses might be interested in competing for Air Force SBIR funds if it were less costly for them to participate or if they could prepare and submit a white paper. The preparation of a white paper would be much less expensive because much of the material probably already exists. The format of the submission could be strictly controlled to, say, a two-page technical

write-up and a one-page write-up about the business, its products, and expertise. Several small businesses estimated that this process would cost less than $500. White papers would also be easier to handle because they would not require debriefing. From the white papers, the Air Force could request 1,000 Phase I proposals per year, from which the 500 most relevant could be selected for awards, at a much lower administrative burden.

Finding. Each year approximately 2,500 to 4,000 proposals are received and evaluated. The current selection rate is one out of nine, which means eight out of nine proposals are rejected. This places a huge administrative burden on Air Force units and laboratories and a substantial economic burden on small businesses.

Recommendation. Only companies whose ideas were originally submitted as a white paper and were shown to be of interest to the Air Force should be invited to submit Phase I proposals. The format for the white paper should be strictly limited to, say, a two-page technical write-up and a one page write-up about the small business, its products, and expertise.

Contract Award Delays

The long gestation time between the submission of a proposal and the award of a contract creates a burden for some small businesses. In addition, the gap between the end of a Phase I contract and the beginning of the Phase II contract is typically around 6 months but can be as long as 1 year. This hiatus makes it difficult for small businesses to retain people with specialized skills and often results in the loss of key personnel. In many cases, this factor alone discourages some small businesses from attempting to enter the SBIR program. The Air Force could allocate funding to bridge the gap between the end of a Phase I contract and the award of a Phase II contract. A typical strategy might be to withhold $30,000 of the $100,000 now allocated for Phase I and ask for Phase II proposals up to the last day of the Phase I. If a Phase II award could be decided on in 6 weeks, the Air Force could immediately release the $30,000 for another 90 days as a modification to the Phase I contract while the Phase II contract is being negotiated.

Executing the Phase I award as a grant rather than as a contract could facilitate the implementation of this strategy. The only deliverable for a grant awarded for research projects is usually a final report. Grants from several federal agencies, such as NSF, DOE, and NASA, allow for automatic payments at appointed intervals (usually 2 months), which greatly improves the cash flow for small

businesses. Modifying a grant is also less bureaucratic than modifying a contract for which several deliverables are involved. DOD contracts usually require submission of invoices and reports every month or every 2 months, even for short, 6-month projects. Because Phase I usually involves only proof of feasibility and a report, a grant would be a better, more efficient mechanism from the small business point of view.

Recommendation. The time line of the entire SBIR process should be shortened and the efficiency improved for both the Air Force and the small business community by issuing Phase I awards as grants instead of contracts. This would also lead to payment processes that are more responsive to the needs of small businesses and would reduce the paperwork and shorten the response time for Air Force program implementers.

Recommendation. By the end of the Phase I award, the Air Force and the awardee should be clear about the probability of Phase III funding in order to plan for its execution. For the Air Force, this would mean the allocation of funds; for the small business, it would mean an understanding of milestones to be met during Phase II to reach Phase III. The Air Force should require milestone dialogues between the customer (Air Force) and the small business to increase commercialization from the current paltry rate of 1.5 to 2 percent to a rate of 20 to 25 percent. This would have a major impact on the Air Force mission.

Management of SBIR Programs and Customer Participation

Staffing for SBIR programs is inadequate at many levels in the Pentagon and at the ALCs. SBIR programs are often assigned to the least experienced engineers, who are not aware of the needs of the Air Force, the ALCs, the SPOs, the aging aircraft program, and other relevant programs. At one ALC, the SBIR program manager was the third person assigned to that responsibility in 4 years. The champion, the one who initiated the program for a particular manufacturer, depot, agency, or laboratory, is often left out of the loop.

Recommendation. Engineers whose tenure is expected to be long should be selected for important innovation programs, especially at the air logistics centers (ALCs), where SBIR-developed innovations are likely to be transitioned to service use. If possible, the initiator or technical champion should be responsible for managing an SBIR program through its life cycle. If an ALC is unable to staff

its SBIR programs, the Air Force Research Laboratory could provide staff on behalf of the ALC.

Finding. The product center or other primary customer of a technology is not always involved in the decision to invite proposals for Phase II.

Recommendation. To ensure that the Air Force derives maximum benefit from its SBIR programs, the product center commander, system program officer, or operation manager should be apprised of Phase I developments and involved in the decision by Air Force Research Laboratory to solicit Phase II proposals. Small businesses could then fine-tune their Phase II programs to meet the specific needs of the customer.

Improving Awareness and Outreach

The nature and operation of the Air Force SBIR program are not well understood at many sites where military and civilian personnel are expected to be directly involved with the program. The same is true of many existing contractors and small businesses that may contemplate participating in the program. Many small businesses are not fully aware of the needs of the Air Force, and many Air Force personnel are not aware of the capabilities available in the small business sector. Information about the ins and outs of military SBIR programs is lacking, as is personal contact with an appropriate engineer to avoid blind proposals. Most small businesses are not aware of the value of working with an end-user organization as early as possible, even at the Phase I stage. Unlike the laboratories, the ALCs do not publicize their needs through road map briefings.

Most SBIR funds are spent for what would otherwise be classified as PE 6.1 or 6.2 research. Many people, both in and out of government, believe that the most important word in the title SBIR is "research" and that the "I" stands for "innovative" rather than "innovation." The distinction is subtle but important. The product of "innovative research" can be a theory, an experimental result, or a research paper. However, the result of "innovation research" will be a useful product expected to improve an Air Force mission.

Finding. Because of the lack of communication between small businesses and end users, Phase I proposals are often inappropriate and unfocused.

Recommendation. Workshops should be conducted with both small and large businesses to inform them of Air Force needs and ensure that Air Force personnel understand the mechanics of the SBIR process and the small business capabilities available to them. Large businesses can catalyze the efforts of small businesses by providing expertise and insight into important customer (Air Force) requirements. Workshops would lead to better use of SBIR funds for all participants and establish a dialogue that could lead to solutions to real Air Force needs.

In the present system, most Air Force SBIR contract technical representatives do not meet the company until after a Phase II award has been made. Often, the Phase I reports and the Phase II promises are not directly relevant to the needs of the end user. Because the small business is already under contract, Phase II resources may be wasted. Allocation of resources in a Phase I award for travel to the center managing the Phase I award would promote an understanding by the Air Force of the grantee's approach and the success of Phase I developments. At that time, Air Force officials could determine the relevance of Phase I to the longer, 2-year Phase II.

Recommendation. Approximately 3 months into a Phase I award, a grantee's meeting should be held at the center soliciting the topic. The purpose of this meeting would be for the small business to highlight its work up to that point and to interface with the end user within the Air Force. The end user could assist in any midcourse correction to be undertaken in the remaining 3 months of Phase I and in establishing general requirements for Phase II. Program managers and system program officers (SPOs) could then be sure that the funds are being used effectively. Program managers and SPOs could also plan on budgeting funds for approximately 2 years down the road to help move the technology into Phase III. The Air Force liaison for the center should also invite large contractors who would benefit from the Phase I developments in their programs. In this way, benefits from the Phase I award would be enjoyed by the Air Force, small businesses, and large government contractors.

Appointment of an Ombudsperson

The current process calls for the solicitation to remain open for 6 weeks so that the solicitor of the topic and the small businesses can engage in a dialogue. However, most small businesses have had great difficulty in obtaining answers to their questions or even reaching the points of contacts listed in just 6 weeks. This lack of communication limits the number of responses and often results in proposals that do not address the Air Force's needs. Effective communication

would enable the Air Force to adopt a market-pull strategy from within the Air Force and address the specific needs of end customers, as opposed to the current technology-push strategy, which makes the commercialization of technologies developed by small companies extremely difficult.

Recommendation. Each center in the Air Force should appoint and empower an ombudsperson to help small businesses communicate with program managers or end users. An effective ombudsperson would ensure that small businesses receive relevant responses to their concerns. Such an appointment will also increase the benefit and recognition to the SBIR program at the various Air Force customer levels.

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Appendix A

Biographical Sketches of Committee Members

Harry A. Lipsitt, chair, is professor emeritus in the Department of Mechanical and Materials Engineering at Wright State University. His expertise is in the development of intermetallics and metals. He spent 30 years at the Air Force Wright Laboratories working on the development and optimization of metallic and intermetallic materials for use in high-temperature applications.

Earl H. Dowell (NAE) is dean emeritus and professor, School of Engineering, Duke University. Professor Dowell's research interests include dynamics, fluid and solid mechanics, and acoustics. His current work is focused on the dynamics of nonlinear fluid and structural systems and their associated limit cycles and chaotic motions. The potential applications for the results of this research are very broad, principally for aerospace, automotive, naval, and other transportation vehicles.

Thomas N. Farris is professor and head, School of Aeronautics and Astronautics, Purdue University. His expertise includes tribology, manufacturing processes, fatigue, and fracture. His research has focused on the experimental and analytical characterization of fretting fatigue; manufacturing processes (e.g., experimental and analytical work on grinding and superfinishing of hardened steels and ceramics for precision components and modeling of the heat-treatment process); and fatigue and fractures (e.g., finite-element calculations of residual stresses in railway rails).

Mary C. Juhas is associate director, Center for the Accelerated Maturation of Materials, Ohio State University. Her expertise includes corrosion and physical metallurgical phenomena; the effect of microstructure on the corrosion behavior of stainless steels; microstructure evolution and properties in lightweight structural alloy friction stir welds; microstructure/property relationships in intermetallic materials; and effects of grain boundary geometry on segregation behavior.

Merrill L. Minges is retired from the Senior Executive Service, where he served with the Air Force Research Laboratory (formerly the Air Force Wright Laboratory) and with the Aeronautical Systems Division as F-16 technical

director. Now a consultant with Universal Technology Corporation, he has expertise in research, technology transition, and acquisition/sustainment program management in key issue areas associated with aging aircraft. His research expertise includes very-high-temperature materials, hypersonic aerodynamics, reentry, propulsion, and space system technologies.

Kesh Narayanan is director, industrial innovation programs, Division of Design, Manufacture and Industrial Innovation of the Directorate for Engineering at the National Science Foundation. His expertise is in SBIR requirements and research management. The SBIR and STTR programs for the National Science Foundation are managed by his office.

Richard E. Pinckert, Boeing Company, is director, Environmental Assurance and Materials Technology Division. His expertise includes maintenance and repair of aircraft, strength analysis, fatigue and fracture analysis, materials, coatings, effects of environmentally friendly materials on corrosion and fatigue, and producibility. His current responsibilities include providing environmental assurance activities in St. Louis, leading materials and process technology at Phantom Works, Materials and Processes Functional Department, and heading the leadership team of the Materials and Processes Committee.

Michael Rooney is senior materials engineer, Applied Physics Laboratory, Johns Hopkins University. His expertise is in nondestructive evaluation, including ultrasonic, radiographic (film-based and computed tomographic), thermographic, and eddy-current methods; hardware/software integration; and new sensor concepts. His responsibilities include technical support in the areas of material selection, characterization, and failure analysis.

T.S. Sudarshan is cofounder, vice president, and technical director for Materials Modification, Inc., Fairfax, Virginia. His expertise is in materials and processes, SBIR requirements, and research management from a small business perspective. He is responsible for management and technical development of innovative materials, processes, and techniques and the coordination of federally sponsored research programs.

Appendix B

Meeting Agendas

FIRST MEETING
January 25–26, 2000
National Research Council
Washington, D.C.

Tuesday, January 25, 2000

8:30 am	NRC Overview, Study Procedures, Bias and Conflict of Interest Discussion	NRC Study Members and Staff Only
9:45	*Break*	
10:00	Welcome and Purpose of Meeting	Harry Lipsitt, Chair
10:15	Overview of Federal SBIR Requirements	Kesh Narayanan, NSF
11:15	SBIR Requirements—Small Business Perspective	T.S. Sudarshan, Materials Modification, Inc.
11:45	*Lunch*	
12:45 pm	Air Force (Study Sponsor) Needs	Blaise Durante, Air Force
1:15	Overview of 1997 NRC Study on Aging of U.S. Air Force Aircraft	Tom Munns, ARINC
2:15	Interservice, Interagency, and Air Force Aging Aircraft Program Overviews	Dan Brewer, AFRL
3:00	Air Force Aging Aircraft Technologies Team, Acquisition, Requirements, Current Issues Overview	Ed Davidson, ASC/EN (Air Force)
3:45	*Break*	
4:00	FAA Aging Aircraft: Current Technical Issues	Ron Lofaro, FAA
4:30	Navy Aging Aircraft: Current Technical Issues	Dale Moore, NAVAIR
5:00	Discussion and Wrap up of Day 1 Presentations	All
5:30	*Adjourn*	

Wednesday, January 26, 2000

8:30 am	Plan for the Day and Subsequent Meetings	Harry Lipsitt, Chair
9:15	Summary/Follow-up of Day 1 SBIR Requirements	Kesh Narayanan
9:45	Summary/Follow-up of Day 1 Aging Aircraft Technical Issues	Merrill Minges
10:15	*Break*	
10:30	Discussion and Assignment of Authors for SBIR Programmatic Sections	All
12:00 pm	*Lunch*	
1:00	Discussion and Assignment of Authors for Aging Aircraft Technical Sections	All
3:00	Closing Summary, Action Items, Future Plans	Harry Lipsitt, Chair
3:30	*Adjourn*	

SECOND MEETING

March 14–15, 2000
United Technologies Corporation
Dayton, Ohio

Tuesday, March 14, 2000

8:00 am	Welcome, Study Scope, Status, Schedule	Harry Lipsitt, Chair
	The SBIR Program	
8:15	The Air Force SBIR Program	Steve Guilfoos, AFRL, Air Force SBIR Program Manager
9:30	SBIR Program Implementation in the Materials Directorate	Marvin Gale, AFRL
10:15	*Break*	
10:30	Ballistic Missile Defense Office	Scott Theibert, AFRL
10:45	Air Armament Center	Dave Uhrig, Air Armament Center
11:15	Fighter/Bomber Portfolio Perspective	Lt. Col. Vishu Nevrekar, Director F-16 and CMDS Program, AFPEO/FB
12:00 pm	*Lunch*	
1:00	SBIR Program Implementation at the Air Logistics Centers	Lt. Andrew Lofthouse, ALC
1:45	Aging Aircraft/SBIR Q&A Roundtable	All
2:45	*Break*	

The Air Force Aging Aircraft Structures Technical Program

Technical Program Overview: AFRL/ASC

Response to the Tiffany Panel Recommendations: Program Evolution Since That Time

Utilization of the SBIR Program: Broadly and Also Specifically for Aging Aircraft

3:00	Air Force Single Technical Leader Overview	Jack Lincoln, ASC
3:45	ASC Aging Aircraft Overview	Maj. Karl Hart, ASC
4:05	Air Force Corrosion Prevention and Control Program	Deb Peeler, AFRL

4:45	Air Force Repair Program	Capt. Mike Myers, AFRL
5:30	*Adjourn*	

Wednesday, March 15, 2000

The Air Force Aging Aircraft Structures Technical Program
(continued)

8:00 am	Air Force Aging Aircraft NDI/NDE Program	Charlie Buynak, AFRL
8:45	Air Force Aging Aircraft Structural Integrity Program	Clare Paul, AFRL
9:30	Aging Aircraft Wrap up Discussions	
10:00	*Break*	

Closed Deliberations
NRC Study Members and Staff Only

10:15	Closed Committee Discussion, Status of Report Writing
12:00 pm	*Lunch*
1:00	Plan May and June Meetings, Other Action Items
3:00	*Adjourn*

THIRD MEETING

May 15–18, 2000
In Conjunction with 2000 Aging Aircraft Conference
St. Louis, Missouri

Monday, May 15, 2000

12:30 pm	Pick Up Registration Material
1:00	Participate in Plenary Session
5:45	*Break*
6:15	*Conference Reception*
7:45	*Adjourn*

Tuesday, May 16, 2000

8:00 am	Participate in Breakout Sessions on Crack Detection, Bonded Composite Repairs, and Multi-Discipline
9:30	*Break*
10:00	Participate in Breakout Sessions on Mechanically Fastened Joints, Composites Debond, and Health Monitoring
11:30	*Group Lunch*
1:00 pm	Meet with Conference Participants to Obtain Input
3:00	Participate in Breakout Sessions on Fracture Mechanics Analysis, Corrosion Fatigue, and Obsolescence
5:00	*Adjourn*

Wednesday, May 17, 2000

8:00 am	Participate in Breakout Sessions on Assessment of Methodologies and Corrosion Prevention Coatings
9:30	*Break*
10:00	Participate in Breakout Sessions on Corrosion Detection/Assessment and Fracture Mechanics Analysis
11:30	*Group Lunch*
1:00	Meet with Conference Participants to Obtain Input
3:00	**Closed Session** Committee Deliberations, Debrief on Dayton Corrosion Workshop, Status of Report Writing, and Plans for June Meeting
5:00	*Adjourn*

Thursday, May 18, 2000

8:00	Participate in Breakout Sessions on Corrosion Prevention Coatings and Bonded Composite Repairs
9:30	*Break*
10:00	Participate in Breakout Sessions on Fleet Management Strategies and Fuselage Damage
12:00 pm	*Adjourn*

FOURTH MEETING

June 21–22, 2000
Woods Hole Center of the National Academy of Sciences
Woods Hole, Massachusetts

Wednesday, June 21, 2000

Session on Review of Draft of Each Section

8:30 am	Introduction	Harry Lipsitt
9:00	SBIR Program	Kesh Narayanan
9:30	Air Force Aging Aircraft Technical Issues	Tom Farris
10:30	*Break*	
10:45	Air Force Aging Aircraft Program	Dick Pinckert
11:20	SBIR to Address Air Force Aging Aircraft	T.S. Sudarshan
12:00 pm	*Lunch*	

Session on Review of Recommendations

1:00	Discussion of recommendations	All
3:00	*Break*	

Breakout Session on Editing/Completing Each Section

3:15	Members break out to edit/complete assigned sections	All
5:30	*Adjourn*	

Thursday, June 22, 2000

Continue Breakout Session on Editing/Completing Each Section

8:30 am	Members continue breakout to edit/complete assigned sections	All

Session on Review of Full Report and Recommendations

10:00	Committee meets to review report and finalize recommendations	All
12:00 pm	*Lunch*	

Session on Additional Report Editing

1:00	Members make edits and concur on report	All
3:00	*Adjourn*	

Acronyms

AATT	Aging Aircraft Technologies Team
AFRL	Air Force Research Laboratory
ALC	air logistics center
ASC	Aeronautical Systems Center
ASIP	Air Force Structural Integrity Program
CAI	commercialization achievement index
CPC	corrosion prevention compound
DAC	designated acquisition commander
DOD	Department of Defense
EIFS	equivalent initial-flaw size
EMD	engineering and manufacturing development
EN	Integrated Engineering/Technology (an office designation in ASC)
ENFS	Structures Branch of the Flight Systems Engineering Division (ASC/EN)
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FSMP	Force Structural Maintenance Plan
FY	fiscal year
IAT	Individual Aircraft Tracking (rogram)
ITT	integrated technology thrust
ITTP	Integrated Technology Thrust Program
JACG	Joint Aeronautical Commanders Group
LESS	loads and environmental severity survey (database)
MAJCOM	Major Command (part of the Air Force organization)
MAUS	Mobile Automated Ultrasound System
MEMS	microelectromechanical systems
ML	Materials and Manufacturing Directorate (AFRL)

NASA	National Aeronautics and Space Administration
NDE/NDI	nondestructive evaluation/nondestructive investigation
NRC	National Research Council
NSF	National Science Foundation
O&M	operations and maintenance
OEM	original equipment manufacturer
PE	Program Element
PEO	program executive official (office)
PM	program manager
POC	point of contact
POD	probability of detection
R&D	research and development
RDT&E	research, development, test, and evaluation
S&T	science and technology
SBIR	Small Business Innovation Research (program)
SCC	stress-corrosion cracking
SMA	Aging Aircraft Product Support Group (ASC)
SPO	system program office (officer)
STTR	Small Business Technology Transfer (program)
TD	technical directorates (AFRL)
VA	Air Vehicles Directorate (AFRL)
VOC	volatile organic compound
WFD	widespread fatigue damage